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Comprehensive Human Factors Guidelines for Road Systems

Prepared for:

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TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

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1.0 Project Objectives

The National Cooperative Highway Research Program (NCHRP) Project 17-18(8), *Comprehensive Human Factors Guidelines for Road Systems*, concerned the initial development of a new resource document for highway designers, traffic engineers, and other practitioners. The purpose of the planned *Human Factors Guidelines* (*HFG*) document, as stated in the project Statement of Work, is "to provide the best factual information and insight on road users' characteristics, in a useful CD-ROM format, to facilitate safe roadway design and operational decisions." The impetus behind this project was the recognition that current design references have limitations in providing the practitioner with adequate guidance for incorporating road user needs and capabilities when dealing with design and operational issues. These limitations may be of various sorts. Design guidelines may represent minimum requirements that are not always appropriate over the full range of roadway users or applications. Guidance may not be based on adequate human factors data. Guidance documents may not offer sufficient explanation so that practitioners can make effective use of behavioral factors. Conflicting requirements or unusual conditions may make it difficult to comply with ideal design parameters and require some basis for a compromise. Design practice may be driven by concerns about cost and compliance, without a basis for also incorporating safety benefits through user-centered design. Because of such limitations to current design guides, it would be beneficial to provide human factors guidelines to assist the practitioner in identifying and addressing human-centered safety concerns in roadway design and operations. The *HFG* meets this need. The *HFG* is seen as complement to other primary design guides, such as the *AASHTO Geometric Design Guide* (AASHTO, 2001) and the *Manual on Uniform Traffic Control Devices* (*MUTCD*; FHWA, 2003).

The *HFG* is seen as a collaborative, evolving document that is expected to be the product of many contributing authors over a period of years. The document may continue to expand, and be refined, over subsequent versions. The development and growth of the *Highway Capacity Manual* (Transportation Research Board, 2000) provides a successful model for this type of approach.

The objective of NCHRP 17-18(8) was to lay the groundwork for a first edition of the *HFG*. The project developed recommendations for the content, format, organization, and capabilities of the *HFG*. It developed an outline of the document and a detailed work plan for the effort required to produce a first edition. As part of this effort, a draft Introduction and one sample chapter were written. Subsequent development of the complete *HFG* itself was not part of this project.

2.0 Project Activities

This document is the project final report for NCHRP Project 17-18(8), *Comprehensive Human Factors Guidelines for Road Systems*. It summarizes the activities and key products of the project. The products include a proposed outline for the *HFG*, a workplan for development of the *HFG* (Appendix A), a draft Introduction (Chapter 1) for the document (Appendix B), and a draft example chapter (Appendix C).

The impetus for NCHRP 17-18(8) grew from the efforts of the Transportation Research Board (TRB) Joint Subcommittee for Development of Human Factors Guidelines for Road Systems. The Joint Subcommittee consists of representatives from several TRB committees as well as several European countries. The Joint Subcommittee formed in 2000 with the goal of promoting an international effort to develop a set of human factors guidelines related to highway safety. It held a workshop in January 2001, attended by 54 researchers and practitioners, to consider the development of such guidelines. Out of this meeting grew further interest in the concept of a human factors guidance resource for highway designers and traffic engineers. NCHPR 17-18(8) stems directly from this interest. The Joint Subcommittee has produced various reports and meeting minutes. Among the documents put out by the Joint Subcommittee is the *Illustrated Example of "International Human Factors Guidelines for Road Systems Design."* This document, drafted in October 2001, was intended to serve as a first draft of ideas for a guidelines document. It was not meant to definitively describe the ultimate document or limit consideration of issues. Quite the opposite, the intent was to provide a "straw man" document that "hopefully will serve to create discussion and ideas among road designers and traffic engineers on what kinds of topics they would like included in the final Guideline and how these topics might best be presented." The authors noted that "it is expected the final Guideline will look entirely different from this illustration." The *Illustrated Example* served as an important starting point for the efforts of NCHRP 17-18(8). With this background, the project was initiated, working independently of, but in communication with, the Joint Subcommittee. While the Joint Subcommittee provides an invaluable international perspective, the approach to NCHRP 17-18(8) is from a North American perspective. The intent is to provide a basis of human factors guidance that is compatible with and complementary to the practices and major reference sources used by highway designers and traffic engineers in the United States.

To accomplish its goals, the project consisted of a sequence of eight tasks:

<u>Task 1. Conceptual Framework</u>– This task consisted of a variety of critical and analytic activities to develop a general approach and framework for the *HFG*. These activities included:

- Critical evaluation of the Joint Subcommittee document, *Illustrated Example of "International Human Factors Guidelines for Road Systems Design."*
- Review of existing human factors guidelines for traffic engineering applications, to provide models for format, content, style, features
- Review of major design guides that the *HFG* will have to complement

- Coordination with the TRB Joint Subcommittee for Development of International Human Factors Guidelines for Road Systems
- Identification of major treatments of human factors for highway design and traffic engineering, including books, chapters, and training courses
- Analysis of the manner in which practitioners are likely to use the *HFG*, including the conduct of a User Needs Workshop
- Examination of options for CD-ROM and multi-media capabilities

<u>Task 2. Submit Report, Outline, and Recommendations</u> – The results of Task 1 were integrated and summarized in report form. The report was reviewed by the TRB project panel, the Joint Subcommittee, and interested reviewers from other TRB committees. The revised version of the Task 2 report, reflecting the reviewer comments, is in Lerner, Llaneras, Hanscom, Smiley, Neuman, and Antonucci (2002a). The report included a discussion of findings and recommendations for the approach to the *HFG* and alternatives for format and structure. It also included a proposed outline for the first edition of the *HFG*. Key recommendations from the Task 2 report are summarized in Chapter 3 of this document. The proposed outline is presented in Chapter 4 of this document.

<u>Task 3. Prepare Work Plan</u> – In Task 3, a work plan was developed that delineated what would be required to develop an initial addition of the *HFG*. This effort began by incorporating reviewing comments on the Task 2 report and revising the initial outline and approach to reflect this review. The work plan then systematically addressed the needs to accomplish that end product. It included identification of required activities, the various technical and editorial roles that are needed, needs for outside collaboration and review, and estimates of time and effort for each activity.

<u>Task 4. Submit Revised Outline and Work Plan</u>– The Task 3 effort was developed in report form and submitted for review by the TRB project panel and the Joint Subcommittee. The Task 4 report (Lerner, Llaneras, Hanscom, Smiley, Neuman, and Antonucci, 2002b) included a response to reviewer comments on the Task 2 report, a revised *HFG* outline, alternative suggestions for a sample chapter, and the Work Plan for developing the initial edition of the *HFG*. Chapter 5 of this document addresses the work plan, and details are included in Appendix A.

<u>Task 5. Prepare Annotated Outlines</u> – Various alternatives for a sample chapter were considered, each with certain advantages. Extensive discussion of this issue was included at briefings and correspondence with the panel and the Joint Subcommittee. Ultimately the decision was made to do a chapter on the relationship of driver time requirements as related to highway design sight distances. Chapter 6 of this document discusses the selection of the sample chapter. Annotated outlines were then developed for the HFG Introduction (Chapter 1 of the proposed *HFG* outline) and the sample chapter (Chapter 5 of the proposed *HFG* outline).

Task 6. Submit Annotated Outlines – The annotated outlines were submitted for review by the NCHRP panel and the Joint Subcommittee. Comments were incorporated prior to writing the chapters.

Task 7. Develop Draft Introduction and Sample Chapter – In this task, the draft introduction and sample chapter were written. Chapter 6 of this document describes the effort. The draft chapters themselves are included as Appendix B (Chapter 1) and Appendix C (Chapter 5).

Task 8. Submit Final Report and Implementation Plan– Task 8 integrated all of the project activities and products into this project final report.

3.0 General Recommendations for Designing the *HFG*

This chapter, drawn from the project Task 2 report (Lerner et al., 2002a), summarizes the project team's understanding of what the *HFG* should be trying to accomplish and how to best achieve these objectives.

3.1 Target Users of the *HFG*

The general purpose of the *HFG*, as defined in the project Statement-of-Work, is to provide the "best factual information and insight" regarding road user characteristics so as to "facilitate safe roadway design and operational decisions." Therefore, although there may be many groups who may make use of the document, the <u>primary</u> audience is those practitioners dealing with design and operational issues in their normal course of work.

This audience is not assumed to have expertise in human factors. There may be little understanding of what the field is and little motivation to seek insights, data, or guidance in this area. While the need to incorporate road user capabilities into design and operational decision making has certainly become more widely appreciated in recent years, appreciation and knowledge are by no means universal. Therefore if the *HFG* is to be used as an everyday resource, it must appeal to and be understood by the range of practitioners, including those with little background in human factors issues. It should also be noted that not all those providing traffic engineering functions are trained engineers. The *HFG* should be written in a straightforward and non-academic manner, but must remain appropriate for trained professionals. It should be at the level of an introductory textbook.

There is an important distinction to be made between the role of the highway designer and that of the traffic engineer. They address road user requirements at different points in the process and use their own distinct tools in addressing driver needs. Both groups need to be cognizant of user-centered concerns in the design and operations of roadways. Designers and traffic engineers are likely to approach the *HFG* in different ways and for different reasons. Both groups must be recognized as distinct parts of the audience for the document.

3.2 Functions and Objectives of the *HFG*

There are various functions that a document called *Human Factors Guidelines* might serve. Questions about exactly what the *HFG* will attempt to accomplish were quite in evidence at the January 2001 TRB workshop conducted by the TRB Joint Subcommittee for Development of International Human Factors Guidelines for Road Systems, A3B02(2). This is reflected in questions such as, is this material "tutorial or referential in nature?" The emphasis placed on various functions will guide the shape of the document. The general functions that the *HFG* might serve include the following:

- Problem solving: identify the probable causes and countermeasures when faced with a problem related to road user characteristics
- Proactive guidance to include human-centered concerns in design and planning and to avoid potential user-related problems
- Promote the understanding of an appropriate road user-centered perspective of safe design
- Educate about fundamental human factors principles related to highway safety
- Provide a defensible basis for deviating from normal practice when that normal practice is not optimal from a road-user based, highway safety standpoint
- Provide adequate documentation as a resource for defense of a design or operational decision
- Provide an independent and authoritative basis to reject politically pressured inappropriate design or operational suggestions

We view all of these functions as interrelated and all must be addressed to some degree by the *HFG*. The first two items above (problem solving and proactive design guidance) are the "day-to-day" uses of the *HFG* and should be the primary drivers of the document's structure. While the *HFG* will serve an important educational function, it should not be viewed as a textbook or a source of technical literature. There already exist a variety of substantial books on human factors for highway safety and traffic engineering. The *HFG* is not intended to be a repository for all relevant human factors and differs from these more didactic references. Its focus is on guidance and the guidelines are organized around traffic engineering/highway design concepts, rather than around human factors concepts. The *HFG* must include educational material on human factors concepts, but it must be streamlined and the guidelines themselves must be structured around engineering factors.

The *HFG* should be viewed as a complement to major design references. It should not duplicate or replace them. This means that the *HFG* does not have to explicitly address every design aspect treated in other sources. For example, it may not be appropriate to specify the placement of a particular traffic control device (e.g., arrow board) for a work zone if this is specified elsewhere. However, the *HFG* does need to deal with the limitations of existing guidance, define conditions where other factors come into play, and help the practitioner in recognizing the need for trade-offs and making decisions. While guidance should include quantitative information wherever possible, this does not mean that the guideline needs to be prescriptive. In many cases the need for additional human factors consideration comes from the fact that there is an unusual situation or conflict among guidelines so that a "cookbook" approach is not appropriate. The guidelines need to provide the principles and data to allow the engineer to work through the problem. The *HFG* should serve as a supplement to primary design guides, and as such the specific guidance needs to be problem-based or treated on a by-exception basis, rather than attempting to specify and justify every aspect of roadway design and operations. It must be more of a tool than a cookbook.

Recognizing that the *HFG* may often serve a problem-solving need rather than an educational one, it therefore should not be assumed that users will enter the document at the beginning and read the introductory and background chapters. Users will typically enter searching for specific guidance on a particular issue. Therefore it will be important to provide cross-referencing to sections that deal with fundamental human factors principles that may relate to some specific guideline. The early sections of the *HFG* should be written in an inviting manner and at a level of detail that does not deter prospective readers. None the less, no guideline statement should presume background chapters have been read.

3.3 Media and Capabilities

The project Statement-of-Work specified that the *HFG* would be developed in a CD-ROM format. While a variety of alternative media were reviewed as part of Task 1 (see Lerner et al., 2002a), CD-ROM has been the focus and offers a variety of virtues as a format for the *HFG*. Although some users may simply want to print hard-copy versions of the handbook (or relevant sections), others may want to access more advanced features of the *HFG* (search the handbook, gather in-depth reference materials, view graphic illustrations or simulations of guideline concepts, or link to other resources). The tool must support these levels of interaction while retaining high-end features and capabilities that can be accessed by others desiring the full range and functionality of multimedia. A multimedia program can provide a nonlinear environment with a united structure that is easy to use, and provides depth of content for the user.

The CD-ROM is a convenient format for delivering high quality visual and interactive multimedia content. As a result of the large file sizes which can be used on a CD-ROM, the content can be far more media-oriented, providing video clips, detailed 3D animations and a host of other technologies. CD-ROM can also be linked to the Internet, providing additional advantages of fast delivery from a CD-ROM yet retain the flexibility to the Internet for updating information. This combination is ideal for accessing related information and handbooks. Content on a CD can also be designed and structured so that it can be converted to web-based delivery. The low replication costs of CD-ROM's and the wide availability of computers with CD-ROM drives make this an extremely practical format. While the information stored on CD-ROMs cannot be updated, links to other documents and the Internet can be provided; this flexibility enables time sensitive information to be readily updated. The flexibility afforded by CD-ROM and the multimedia capabilities which it brings makes this an ideal tool for this type of application. A CD-ROM based human factors handbook has the potential to provide traffic engineers with an informative and interactive tool that will help them to apply known research and guidelines to solve design issues, as well as provide opportunities for them to access extensive reference materials and link to other frequently used resources (manuals, handbooks, etc).

The ability to search the *HFG* document is viewed as a crucial and beneficial feature that can help users access desired and relevant information quickly and easily. This capability is greatly facilitated by electronic search engines, and is expected to be a significant advantage of the CD-ROM over hardcopy. Unfortunately, there is no standardized set of features or user interfaces common to most search engines. Some can possess complex or difficult to use interfaces, and lack important search features leading to confusion and frustration. Since providing users with control over their searches increases overall satisfaction as well as performance, the HFG should provide users with useful features that enable them to quickly access needed information.

Table 1 highlights some important features which may help drive the selection of appropriate search engines; features are organized in terms of capabilities useful when defining the search itself, as well as characteristics associated with displaying search results.

Table 1. Summary of CD-ROM Search Engine Features

FEATURES	DESCRIPTION
Search Features	
Define Sources (Advanced Search)	Ability to restrict or limit the scope of the search (specific documents, chapters, entire document, etc.).
Full-Text Search	Capability to conduct searches using free form words (text strings).
Keyword Search	Search by specific word. Requires the establishment of "keywords."
Boolean Search	Complex logical searches that combine words using special operators (And, Or, Not)
Phrase Search	Search for a phrase (usually enclosed in double quotation marks).
Index Search	Guides search using headings and subheadings. Index linked to search.
Wildcards	Supports use of an asterisk at the end of a word or part of a word to "match anything"
Refine Searches	Ability to tailor the search once the initial search is launched; refine without the need to start over.
Results	
Relevance Raking	Supports a mechanism to prioritize and display results (e.g., most relevant results are shown first).
List of Results with Feedback	Presentation of result in list form with a brief description of the result.
Number of Hits	Specifies the result set size.
Highlights search terms in context	Hits (search terms) are highlighted in the text. May allow user to move between instances of the words on the pages.
Includes Viewer to Display Graphics	Provides a means to view graphics as well as text results.
Abstracts	Ability to read a condensed description of the document or preview documents (aids in determining relevance).
Other	
Customizable Features	Search forms and results page.
Stop Function	Stops the search if user feels its taking too long.
Back Button	Goes to previous screen.
Sequencing results	Allows user to tailor the order of presented results (grouped or sorted results).

A suitable search engine must not only provide desirable search utilities and features, it must also be compatible with a range of user platforms and support a variety of anticipated file types (PDF, HTML, Word Processor, Database, Spreadsheet, etc.). The ability to migrate from CD-ROM to web-based application is also beneficial and should be considered when designing the architecture and format of the CD.

The CD-ROM provides a flexible vehicle for housing the HFG document; the medium is widely available to the user population, and is capable of supporting the types of file formats and search utilities envisioned for the HFG document. If structured appropriately, content on the CD-ROM can also be migrated to a web-based environment, if future needs demand. Another practical advantage of a CD is that it facilitates document version control; a web-based tool would be more difficult to manage revisions to the document.

3.4 Content and Organization of the *HFG*

A specific outline for the *HFG* is provided in Chapter 4. That structure was driven by considerations presented in this section.

The *HFG* needs to be streamlined and highly usable as a day-to-day reference. The guidance portions need to be succinct and present only as much background as enables intelligent application of the guideline. Treatment of human factors and systems perspectives need to be readable and useful but not encyclopedic. However, it was also quite clear from the user needs workshop conducted under Task 1 of this project that practitioners find it very important to have direct access to more detailed information for those times and situations where support is needed. The technical background must be easily related to specific guidelines. The willingness of an engineer to select some optimal design over a minimum specification or usual approach will depend to some extent on the ability of the document to provide "backup" for that decision. For this reason, the *HFG* is envisioned to be a reasonably streamlined guidance document, but associated with a related companion document or documents. It is assumed that the author of any chapter of the *HFG* will conduct a detailed technical literature review as a basis for the development of their guidelines. Therefore it is assumed that these literature reviews will be available as a companion resource, even though not part of the *HFG*. The Federal Highway Administration document, *Guidelines and Recommendations to Accommodate Older Drivers and Pedestrians*, serves as a partial model for this approach. This document is essentially a series of guidelines, with a few pages of background discussion and many individual guidelines, each about a page or two in length. A related document, *Highway Design Handbook for Older Drivers and Pedestrians*, supplements the guidelines with an extensive literature review, from which the guideline recommendations were derived. This larger document is about four times the size of the smaller document. Although the *HFG* will necessarily contain much more background material that the *Guidelines and Recommendations to Accommodate Older Drivers and Pedestrians*, this example illustrates the usefulness of the companion document as a means of keeping the guidelines document usable. The CD-ROM format will enhance easy access to companion volumes. The proposed approach to the organization of the *HFG* is based on the assumption that a companion volume approach is an effective way to resolve the desire of users for a streamlined, easily searched, highly usable source of day-to-day guidance with the need for occasional access to detailed backup information and formal research citation and analysis.

For purposes of understanding road user capabilities and the role of user-centered thinking in the highway safety system, it is necessary to organize some portion of the *HFG* around the roadway user. However, the set of guidelines themselves should be organized around characteristics and elements of the roadway. This is more consistent with the manner in which the practitioner approaches the task and searches the document. CD-ROM capabilities for internal linking or cross-referencing need to be taken full advantage of here, in order to direct the reader, when necessary, to relevant roadway user considerations even though the approach is through a highway design element.

The recommended structure of the *HFG* is comprised of four major sections, or Parts. It is a structure that meets the various functions of the *HFG* and provides a meaningful basis for the approach and needs of both the traffic engineer and the highway designer. The structure is intended to be consistent with the manner in which users might approach and search the document, given their likely motivations. Each of the four Parts is comprised of chapters; there are a total of 21 chapters proposed for the initial *HFG*. While not exhaustive, these chapters would be reasonably comprehensive and provide an effective aid to designers and traffic engineers. Table 2 presents an overview of the structure. The outline shown in Table 2 is the same as that presented in the project Task 4 report (Lerner et al., 2002b), with two exceptions. First, the title of Chapter 5 has been revised to reflect the working title of the sample chapter (Appendix C). Second, an additional chapter, "Speed Perception, Speed Choice, and Speed Control," has been added to the outline. It is inserted as "Chapter X." We did not give it a specific chapter number in order to maintain the chapter numbering from the Task 4 report. It would probably fit best between the numbered chapters 5 and 6. When the initial outline was developed, it was felt that the human factors issues of speed perception and speed choice could be treated adequately in Part II of the *HFG*. However, as work proceeded on the sample chapter, it became evident that a more extensive treatment, relating the details of speed perception and speed choice to traffic engineering and design decisions, would be very helpful. Therefore such a chapter has now been included.

Part I is introductory and intentionally brief, with two short chapters. The purpose of the first chapter is to describe the needs for the *HFG* and the purposes it is intended to serve. It will define "human factors" and its role in design and safety in high-level terms (Part II will provide greater detail). The chapter will clarify the relationship of the *HFG* to other design guides and reference sources and explain its role as a complement to primary standards and engineering guides. The second chapter of Part I will explain to the reader how to use the *HFG*. It will describe the organization and will detail the automated search capabilities. The availability and role of the companion literature review papers will be explained. The relationship to other sources of guidance will be described and the system of cross-referencing within the *HFG* will be discussed. A set of references to other resource materials will be provided, with a capsule description of how each relates to the *HFG*. We note that a shortcoming of other traffic engineering reference documents that have been produced as CD-ROM or web-based versions is that search capabilities and how to use them are not made evident. Users may not be aware of what functions they have available or exactly how they work. For example, there may be Boolean functions that may permit a more refined search (using an "and" function) or the ability to screen many irrelevant "hits" (using a "not" function). Yet the document has no description or link to such information. We feel that the clarification of how the document can be effectively searched should be an important part of Chapter 2. Overall, then, the intent of Part I is simply to provide a succinct basis for use of the *HFG*: what it is and how it works.

Table 2. Proposed Parts and Chapters for the *HFG*

PART I: INTRODUCTION TO THE *HFG*
- Chapter 1. Why Have Human Factors Guidelines for Road Systems?
- Chapter 2. How to Use This Document

PART II: BRINGING ROAD USER CAPABILITIES INTO HIGHWAY DESIGN AND TRAFFIC ENGINEERING PRACTICE
- Chapter 3. A System Approach to Highway Safety: Thinking Like a Road User
- Chapter 4. Basic Road User Capabilities

PART III: HUMAN FACTORS GUIDANCE FOR ROADWAY LOCATION ELEMENTS
- Chapter 5. From Driver Reaction Time, Maneuver Time, and Speed to Design Distances: General Guidelines
- Chapter 6. Curves (Horizontal Alignment)
- Chapter 7. Grades (Vertical Alignment)
- Chapter 8. Tangent Sections and Roadside (Cross Section)
- Chapter 9. Transition Zones Between Varying Road Designs
- Chapter 10. Non-Signalized Intersections
- Chapter 11. Signalized Intersections
- Chapter 12. Interchanges
- Chapter 13. Construction and Work Zones
- Chapter 14. Rail-Highway Grade Crossings
- Chapter 15. Special Considerations for Urban Environments
- Chapter 16. Special Considerations for Rural Environments
- Chapter X: Speed Perception, Speed Choice, and Speed Control

PART IV: HUMAN FACTORS GUIDANCE FOR TRAFFIC ENGINEERING ELEMENTS
- Chapter 17. Signing
- Chapter 18. Changeable Message Signs
- Chapter 19. Markings
- Chapter 20. Lighting

Part II deals with road user capabilities and the role of road user-centered thinking in the systems conception of highway safety. It corresponds roughly to Chapters 2 and 3 of the *Illustrated Example* although there are some differences in sequence and content. Part II is comprised of two chapters. The initial chapter introduces the system approach and emphasizes "thinking like a road user." It is meant to be a very "readable" chapter, without a lot of jargon, models, or data. One of the real issues for the *HFG* is how to motivate a practitioner to read it, other than in a very specific problem-solving mode. We want to be able to influence the thinking of the traffic engineer, and maybe even more importantly the highway designer, so that they adopt a more global, system-perspective view and the ability to incorporate road-user needs into their approach. This chapter is where we hope to accomplish this. While there is no means of forcing someone to read any portion of the *HFG*, this chapter will be designed to be inviting and readable. It should use "punchy," succinct text and make maximum use of the multimedia capabilities of CD-ROM. For example, these might include driver's eye view video clips, animations, dynamic graphics, side-by-side comparisons, and so forth. The chapter will include a section on "thinking like a road user" that will introduce a few key concepts and issues in a very practical, jargon-free manner. The second chapter within Part II defines and quantifies basic driver capabilities directly related to engineering practice and decision making. It explains fundamental behavioral factors, such as perception-reaction time and expectancy. It provides basic empirical data on human perceptual and performance characteristics. While many readers may not read this chapter beginning to end, it will serve as an essential link to later guidelines and principles and can be cross-referenced as needed.

Parts III and IV are related in that they provide the set of specific guidelines, organized around factors relevant to the designer or traffic engineer. These Parts are the core of the *HFG* for practical use. One issue in structuring this portion of the *HFG* is how to organize the guidelines and how much detail should be in the chapter structure. Our analysis, strongly confirmed in the user workshop, was that the guidelines should be organized around the primary types of roadway locations, but that while this is desirable, it is not sufficient. Practitioners are frequently likely to want to enter the guidelines with respect to some type of roadway location, such as a "signalized intersection" or a "construction and work zone." Therefore these should be represented by a set of chapter headings. Elements of design that highway designers tend to think of, such as cross section and alignment, should be identifiable but not the basis of the structure. Part IV then presents a range of cross-cutting issues that relate to traffic engineering elements (e.g., signs, lighting). Many of the guidance principals are not location-specific and would be redundant to consider within each chapter. Furthermore, the user may conceive of his or her issue in terms of a device or other engineering element and seek guidance with respect to human-centered principles for the device. Therefore a set of guidelines chapters is organized as a section (Part IV) on traffic engineering elements. In summary then, the guidelines are organized into chapters under two distinct parts: Human Factors Guidance for Roadway Location Elements and Human Factors Guidance for Traffic Engineering Elements. Cross-referencing and links between these sections are assumed and remain critical for steering the user to all appropriate guidance without an unduly redundant and unwieldy document.

3.5 Chapter Structure and Features

The guidelines chapters (under Parts III and IV) should share a common format and a common approach to presenting the issues and guidance. As the *HFG* is developed, different authors will be responsible for the various chapters. The individual authors, as topic experts, will have to determine for their chapter precisely what the specific guidelines needs are. However a common format will aid the user and may help ensure a comprehensive treatment. Chapter 5 of this report will present a specific recommendation for the chapter format.

The core of each chapter (in Parts III and IV) is a set of guidelines statements. The format for the individual guidelines is discussed in the next section. Although the guidelines are the major component, there are other sections important to the standard chapter structure. As noted in Section 3.4, it is assumed that for each chapter there will have been a literature review conducted. The detailed information and citations in that review do not need to be included in the body of the chapter in the *HFG*, but a link to the full review is necessary. However, each chapter should begin with a brief "background" section that puts the safety and driver-centered issues in context. This background should highlight the major types of design and operational issues that tend to occur, the nature of the safety problem (crash characteristics), road users that may have special needs (e.g., heavy trucks, pedestrians), and the major human factor issues. If kept brief (e.g., 2 pages), this background section will be more likely to be read. It provides the opportunity for the chapter author to set a context in which the specific guidelines will be more understandable and appreciated.

The Task 2 report also suggested another section for the chapters of Parts III and IV. This was a "Road User Requirements Analysis" that maps human factors needs and strategies in a systematic manner, using headings of

- Required acts
- Driver information requirements
- Driver action requirements and decisions
- Contributing factors
- Addressing potential solutions

In previous projects (e.g., Lerner, Llaneras, McGee, and Stephens, 2002), this sort of analysis proved to be both a very useful tool for developing recommendations and an effective means of communicating the human factors needs and strategies to a non-human factors expert audience. However, we found that the issues of the sample chapter (Appendix C) did not lend themselves readily to this format, and for many planned chapters, the range of issues may simply be too great to employ this technique. Therefore it is suggested that *HFG* chapter authors consider a tabular format User Requirements Analysis as a possible feature for a given chapter. However, it is not suggested that this be a standard part of the structure of all chapters.

The project team also gave consideration to the inclusion of a decision tree or some other type of diagnostic scheme as an element of each chapter. Such tools might prove to be valuable aids to the practitioner. However, it was determined that the development of diagnostic tools may be beyond the scope of the basic *HFG* development effort for many topics. However, it may be appropriate for others. In the course of developing the sample chapter, we found the inclusion of a diagnostic procedure to be helpful. Therefore this should be a chapter-by-chapter decision. In the Task 2 report, it was suggested that NCHRP or other agencies give serious consideration to a systematic program of parallel development of diagnostic tools and other decision aids that might complement *HFG* chapters. This would allow more thorough development, and validation, than might be possible within a limited chapter-writing effort.

The project team, in discussing the details of the chapter structures in Parts III and IV, concluded that NCHRP 17-18(8) should not overly specify the organization and specific set of guidelines to be included in the chapter. That is exactly what the authors must do, based on their expertise, the literature review, and the systematic road user requirements analysis. Also, it is important that the relevant TRB technical committees should coordinate with chapter authors to provide input to set of guidelines needed. We feel the structure of the initial portions of a chapter will help clarify an organization for the individual guidance items and help make more evident where a guideline is required. As noted earlier, the *HFG* need not try to comprehensively address every aspect of design and operations, which would be redundant with other guides and would result in a voluminous set of guidelines. The guidelines in each chapter should be developed based on a perceived need. Issues are treated by exception or where there are combinations of elements or other concerns not adequately dealt with in other sources.

4.0 Proposed Outline of the *HFG*

The outline that follows proposes a structure and content for the HFG. It also offers a tentative title: *Human Factors Guidelines for Road Systems: Design and Operational Considerations for the Road User*. The phrase following the colon was introduced to address potential misunderstandings of the term "human factors" by possible users who have little familiarity with the field.

As noted in Section 3.4, the outline that follows differs from the revised outline in the project Task 4 report (Lerner et al., 2002b) in two respects. First, the title of Chapter 5 has been revised to reflect the working title of the sample chapter (Appendix C). Second, an additional chapter, "Speed Perception, Speed Choice, and Speed Control," has been added to the outline. It is inserted as "Chapter X." Section 3.4 discussed the rationale for this new chapter. As noted there, this additional chapter has not been given a specific chapter number in order to maintain the chapter numbering from the Task 4 report. It would probably fit best between the numbered chapters 5 and 6.

The proposed structure organizes the *HFG* into twenty-one chapters grouped under four major Parts. Part I (Introduction to the *HFG*) provides background on the needs for a human factors guidelines document, the purposes of the *HFG*, and an explanation of how to use the document. Part II (Bringing Road User Capabilities into Highway Design and Traffic Engineering Practice) is based around the road user. This is in contrast to the subsequent sections, which are organized around roadway factors. Part II describes the user-centered approach of human factors in a roadway system context and helps the practitioner think about the roadway from a road user's perspective. Basic driver capabilities that directly relate to engineering practice are presented.

Parts III and IV present the actual guidelines within the *HFG*. Part III is organized around specific roadway location elements, such as signalized intersections and work zones. This structure is most compatible with the likely problem solving mode and conceptual model of practitioner users. The first chapter within Part III deals explicitly with the key design considerations of speed (design speed vs. operating speed), sight distance, perception-reaction time, and their interrelationship. Then the remaining 11 chapters in this Part address specific roadway locations. Within this structure, design elements such as horizontal alignment, vertical alignment, and cross section are treated within the most appropriate chapter (e.g., horizontal alignment in the "Curves" chapter), and unique location-specific considerations are treated within other chapters. Part IV deals with traffic engineering elements, including signs, variable message signs, markings, and lighting. Thus Parts IV deals with the general non-location-specific human factors principles of these traffic engineering elements while Part III concerns location-specific applications. Cross-referencing and linking among the chapters of the various sections is assumed and will be critical. The practitioner facing an issue may conceptualize it in various ways and search the *HFG* for various terms. The links and cross-references avoid redundancy and steer the user to the appropriate guidance.

It is believed that the proposed technical chapters encompass the major highway design and traffic engineering issues that have important human factors considerations. They provide a reasonable scope for an initial version of the *HFG*. Although additional topics may be added later, the range of topics proposed here will make the initial *HFG* a reasonably comprehensive document for assisting practitioners in defining and addressing likely concerns.

HUMAN FACTORS GUIDELINES FOR ROAD SYSTEMS: DESIGN AND OPERATIONAL CONSIDERATIONS FOR THE ROAD USER

PART I: INTRODUCTION TO THE *HFG*

This part of the HFG explains the need for the HFG and the purposes for which it is intended. It then describes how to use the document, including the relationship to other design guides and linkages to background literature reviews.

CHAPTER 1: WHY HAVE HUMAN FACTORS GUIDELINES FOR ROAD SYSTEMS?

1.1 What is Human Factors?

1.2 Why are Human Factors Guidelines for Road Systems necessary?

- User-based design in a system safety context
- Limitations to design guides
  - Limited empirical basis
  - Issues unaddressed by guidance
  - Minimum specifications vs. range of applications
  - Substantive safety (crash experience) vs. nominal safety (conformance to standards or accepted practices), cost effectiveness
- Absence of comprehensive treatment in guideline format for practitioners

1.3 Purposes of this document

- Recognize and address human factors-related issues
- Incorporate human-centered concerns into design and planning
- Provide basic information and principles of human factors and road user behavior
- Provide resource for justification in decision making
- What this document is <u>not</u> (textbook, tutorial, replacement or alternative to primary design references)

CHAPTER 2: HOW TO USE THIS DOCUMENT

How to use this document

- Organization and format
- Search capabilities
- Background literature review papers
- Relation to other standards and guidelines documents
- Related resources

PART II: BRINGING ROAD USER CAPABILITIES INTO HIGHWAY DESIGN AND TRAFFIC ENGINEERING PRACTICE

This part of the HFG is based around the road user. It concerns the role of the road user as part of the highway system and presents an overview of the important characteristics and capabilities of drivers and pedestrians. The first portion (Chapter 3) describes how road user characteristics are dealt with in a human factors approach and assists the practitioner in "thinking like a road user." It helps the practitioner see the roadway from the perspective of the road user, especially the unfamiliar road user or the road user with limited capabilities because of inexperience, degraded perceptual ability, medical conditions, and transient states (fatigue, confusion, distraction, impairment). The second portion (Chapter 4) deals specifically with human capabilities basic to driving. It introduces key concepts and quantitative data. Guidelines in subsequent sections will cross-reference or link to the appropriate driver attributes in this section. The presentation in this chapter should be aimed at information that will be useful for practitioners. It should avoid the superficial introduction of technical topics that are not directly usable at the level of presentation (e.g., contrast sensitivity) and should not provide detailed treatments of physiology, basic sensory phenomena, cognitive mechanisms, etc. The emphasis is on application, not psychological process. Important principles should be explicitly indicated. This focused section should not be treated as a human factors text; it can reference or link to more detailed presentations in major reference sources, where appropriate.

CHAPTER 3: A SYSTEM APPROACH TO HIGHWAY SAFETY: THINKING LIKE A ROAD USER

3.1 The Road User as a Component of the Highway System

- Components of the highway system (range of users, vehicle, roadway environment)
- The need for a systems perspective
- Road function as a guiding factor
- Crashes as system failure versus driver error
- Human factors inputs for context-sensitive design

3.2 The Human Factors Approach to User-Centered Design

- Designing for human capabilities, behaviors, and errors
- Human factors considerations and the selection of design speed
  - The linkage of design speed, speed choice, and perception-reaction time
  - The relationship of speed and information handling
- Human factors sources and methods (information base, task analysis, research)
- Models of the road user (limited treatment, with reference to other sources)

3.3 Limitations of Highway Design and Traffic Engineering Guidance for User-Related Issues in Roadway Systems

- Empirical basis of guidance (lacking, dated, limited range of users)
- Minimum criteria may not be adequate for a given situation
- Real world conflicts and complexities
- Examples of cases where it is difficult to adhere to minimum specifications (due to geometric requirements, terrain and environmental features, etc.)

3.4 Thinking Like a Road User

- Why the practitioner and the road user see things differently
  - System overview, site familiarity, understanding of objectives, comprehension of TCDs and operations, motivations, capabilities, compartmentalized views
  - Key questions
    - Where are you in the road environment?
    - What is the function of the road?
- Basic principles distinguishing practitioners and roadway users
  - Driver expectations
    - Road user: expectancy (recent and immediate experience, personal history), mental model of traffic situation, critical role of next few seconds
    - Designer: complete and accurate overview, knowledge of upcoming events
  - Prior knowledge and expertise affect the process
    - Prior knowledge and expertise influence pattern recognition, hazard recognition, automaticity (attentional effects), search patterns
    - Road user make lack driving expertise and prior knowledge: perception as an active constructive process that takes time and is prone to errors
  - Motivations are different
    - Practitioner: Performance (operations and safety) at the network and roadway level; adherence to standards, guidance, usual practice; reducing costs
    - Road user: me first, delay and frustration, navigating, competing (non-driving) tasks
  - Understanding of the roadway
    - Road user: imperfect understanding of TCDs, less ability to read the road, inaccurate risk perception
    - Practitioner: knows meaning and purpose of each element and device, "secret codes," likely hazards
  - Information provision versus information handling
    - Practitioner: formal requirements and standard means of presenting information
    - Road user: searching and processing takes time; information load, primacy, shedding; conspicuity; attention and distraction
  - Capabilities vary
    - Road user: includes novices, reduced visual or cognitive capabilities, motor capabilities (pedestrian walking speed), transient states (fatigue, alcohol, drugs, emotional), lost or confused, environmental degradation (dark, glare, rain, obscuring large vehicles)

- Practitioner: generally good capabilities and not dealing with transient problems

- Summary: Keys to thinking like a road user (steps or table)

CHAPTER 4: BASIC ROAD USER CAPABILITIES

4.1 Human Visual Capabilities

- Including legibility, day & night vision, glare, visual search patterns, range of abilities and anomalies, accommodation

4.2 Attention and Distraction

- Including attention sharing among multiple sources, multi-task nature of driving task, external and in-vehicle sources of distraction

4.3 Information Handling

- Including information processing time, visual scanning, information load, shedding of information

4.4 Expectancy

- Including short term events and long term experience as determinants of expectancy, how expectancies are built, how they influence performance

4.5 Perception-Reaction Time

- Including components of the perception-response process, factors that influence speed of perception and reaction, quantitative PRT functions

4.6 Speed Perception and Speed Choice

- Including perception of own speed, errors in perception of others' speeds and closing rates, determinants of speed choice

4.7 Hazard Perception and Risk Taking

- Including road user abilities to detect various sorts of hazards, speed and reliability of hazard detection, anticipation of risks, judgment of risk, individual risk taking and risk management

4.8 Driver Age and Experience

- Including older and novice road users, range of abilities, effects of age and inexperience on performance, countermeasures

4.9 Driver Impairments

- Including prevalence and effects of fatigue, medication, alcohol, drugs

PART III: HUMAN FACTORS GUIDANCE FOR ROADWAY LOCATION ELEMENTS

Parts III and IV of the HFG present the actual guidelines. Users may be most likely to enter the HFG at the level of Part III, searching for a solution to specific safety or operational concerns they are encountering. The organization of the chapters is based around major categories of roadway locations. The exception is for the initial chapter of this Part, which meets the need to emphasize the central themes of speed and time: principles of design vs. operating speed, sight distance, perception-reaction time, and their interrelationship. The location-specific guidance and discussion of this section will cross-reference the more general guidance regarding traffic engineering elements in Part IV. <u>Combinations of geometries</u> is a critical aspect and key cases must be treated within each chapter.

CHAPTER 5: FROM DRIVER REACTION TIME, MANEUVER TIME, AND SPEED TO DESIGN DISTANCES: GENERAL GUIDELINES

CHAPTER 6: CURVES (HORIZONTAL ALIGNMENT)

6.1 Background [see Chapter 5 of this report for description]
6.2 Road User Requirements Analysis [see Chapter 5 of this report for description]
6.3 Guidelines [see Chapter 6 of this report for description]

CHAPTER 7: GRADES (VERTICAL ALIGNMENT)

7.1 Background [see Chapter 5 of this report for description]
7.2 Road User Requirements Analysis [see Chapter 5 of this report for description]
7.3 Guidelines [see Chapter 6 of this report for description]

CHAPTER 8: TANGENT SECTIONS AND ROADSIDE (CROSS SECTION)

8.1 Background [see Chapter 5 of this report for description]
8.2 Road User Requirements Analysis [see Chapter 5 of this report for description]
8.3 Guidelines [see Chapter 6 of this report for description]

CHAPTER 9: TRANSITION ZONES BETWEEN VARYING ROAD DESIGNS

9.1 Background [see Chapter 5 of this report for description]
9.2 Road User Requirements Analysis [see Chapter 5 of this report for description]
9.3 Guidelines [see Chapter 6 of this report for description]

CHAPTER 10: NON-SIGNALIZED INTERSECTIONS

10.1 Background [see Chapter 5 of this report for description]
10.2 Road User Requirements Analysis [see Chapter 5 of this report for description]

10.3 Guidelines [see Chapter 6 of this report for description]

CHAPTER 11: SIGNALIZED INTERSECTIONS

11.1 Background [see Chapter 5 of this report for description]
11.2 Road User Requirements Analysis [see Chapter 5 of this report for description]
11.3 Guidelines [see Chapter 6 of this report for description]

CHAPTER 12: INTERCHANGES

12.1 Background [see Chapter 5 of this report for description]
12.2 Road User Requirements Analysis [see Chapter 5 of this report for description]
12.3 Guidelines [see Chapter 6 of this report for description]

CHAPTER 13: CONSTRUCTION AND WORK ZONES

13.1 Background [see Chapter 5 of this report for description]
13.2 Road User Requirements Analysis [see Chapter 5 of this report for description]
13.3 Guidelines [see Chapter 6 of this report for description]

CHAPTER 14: RAIL-HIGHWAY GRADE CROSSINGS

14.1 Background [see Chapter 5 of this report for description]
14.2 Road User Requirements Analysis [see Chapter 5 of this report for description]
14.3 Guidelines [see Chapter 6 of this report for description]

CHAPTER 15: SPECIAL CONSIDERATIONS FOR URBAN ENVIRONMENTS

15.1 Background [see Chapter 5 of this report for description]
15.2 Road User Requirements Analysis [see Chapter 5 of this report for description]
15.3 Guidelines [see Chapter 6 of this report for description]

CHAPTER 16: SPECIAL CONSIDERATIONS FOR RURAL ENVIRONMENTS

16.1 Background [see Chapter 5 of this report for description]
16.2 Road User Requirements Analysis [see Chapter 5 of this report for description]
16.3 Guidelines [see Chapter 6 of this report for description]

CHAPTER X: SPEED PERCEPTION, SPEED CHOICE, AND SPEED CONTROL

PART IV: HUMAN FACTORS GUIDANCE FOR TRAFFIC ENGINEERING ELEMENTS

This section provides guidance for major cross-cutting issues for traffic engineering elements that are not specific to particular highway locations. The traffic engineering elements include signs, variable message signs, markings, and lighting. General principles and guidelines will be provided here. Application-specific recommendations will be under the appropriate chapters of Part III.

CHAPTER 17: SIGNING

17.1 Background [see Chapter 5 of this report for description]
17.2 Road User Requirements Analysis [see Chapter 5 of this report for description]
17.3 Guidelines [see Chapter 6 of this report for description]

CHAPTER 18: CHANGEABLE MESSAGE SIGNS

18.1 Background [see Chapter 5 of this report for description]
18.2 Road User Requirements Analysis [see Chapter 5 of this report for description]
18.3 Guidelines [see Chapter 6 of this report for description]

CHAPTER 19: MARKINGS

19.1 Background [see Chapter 5 of this report for description]
19.2 Road User Requirements Analysis [see Chapter 5 of this report for description]
19.3 Guidelines [see Chapter 6 of this report for description]

CHAPTER 20: LIGHTING

20.1 Background [see Chapter 5 of this report for description]
20.2 Road User Requirements Analysis [see Chapter 5 of this report for description]
20.3 Guidelines [see Chapter 6 of this report for description]

5.0 Work Plan

Under Task 3 of this project, a work plan was developed that identified and sequenced the activities that will be required to develop a first edition of the *HFG*. The work plan included general estimates of required time, labor, and costs. This plan was submitted for review as part of the Task 4 report (Lerner et al., 2002b). The work plan, with minor editorial revisions, is attached as Appendix A of this report.

Several aspects of the work plan bear mention:

- The plan assumes a significant central coordination and editing function. The *HFG* is not seen as a collection of more-or-less independent chapters. Rather, in order to have an integrated, highly usable electronic document, with extensive searching and linking capabilities, and with distributed shared information, close technical and editorial coordination is required throughout the document development process.
- The work plan is conceptualized as having five major stages and requiring three parallel, but coordinated, lines of activity. The five stages are:
  - I. Document structure and preparation
  - II. Chapter structure
  - III. Chapter writing
  - IV. Integration and media
  - V. Document evaluation and production

  The three parallel lines of effort are: (1) technical and editorial coordination; (2) chapter authorship; and (3) outside collaboration and review.
- The work plan provides ample opportunities for broad outside review by technical committees, professional and standards organizations, and other stakeholders. Input, comment, and critical review are integrated as part of the work plan.
- Estimates of time and effort are necessarily based on some assumptions regarding the phasing and scope of the effort. For planning and estimating purposes, it was assumed that chapter writing and integration will be done in a series of three waves of about six chapters each. Because of the editorial and integrative requirements, the process will be more efficient if the chapters are developed in groups, rather than one or two at a time. Based on various assumptions in the work plan, it was estimated that each wave of chapters should require about an 18 month period.

Appendix A provides the work plan. It includes full discussion and has charts documenting work flow, level of effort by personnel category, and total estimated effort and cost summaries.

6.0 Example Chapters

Two chapters were written as an initial basis for the *HFG*. One of these was the first, introductory chapter. This is a short introduction to the purpose of the document and its general content and use. The introduction does not contain any detailed technical material or guidance. The other chapter is a sample chapter from the portion of the HFG that provides guidance. The particular chapter selected – “From Driver Reaction Time, Maneuver Time, and Speed to Design Distances: General Guidelines” – was selected as the example chapter after extensive outside consultation and discussion. It is intended to serve as a “straw man” model for subsequent chapters and also to serve as a stand-alone document for its potential interest and use now for its particular topic area. The example chapter is referred to a “Chapter 5” for consistency with the proposed *HFG* outline (see Section 4.0). It is recognized that the chapter number may likely change in the course of the development of the *HFG*, but a chapter number was designated to help clarify the status of this chapter as an integrated element of a larger, interactive document.

Section 6.1 describes the considerations that went into the selection of the sample chapter. Section 6.2 provides introductory discussion for Chapter 1, “Why Have Human Factors Guidelines for Road Systems?” Section 6.3 provides introductory discussion for Chapter 5, “From Driver Reaction Time, Maneuver Time, and Speed to Design Distances: General Guidelines.” The full chapters themselves are attached to this report as appendices. Chapter 1 may be found in Appendix B and Chapter 5 in Appendix C.

The *HFG* is envisioned to be a CD-ROM based document that is highly interactive. Users will be able to move from section to section via linking options and material will be shared between sections. The *HFG* will also be able to employ dynamic displays made possible by the medium. Therefore we may expect animations, video, and interactive elements. Since the example chapters provided here (Appendix B and C) do not share these capabilities, they are simulated in the sample chapters. Links are shown in brackets, using boldface [**Section X.X**]. This is intended to show where a link would allow the reader to obtain more information by jumping to another chapter, or another document altogether if Web-accessible. A few examples of potential animation are included as well. In these cases, text is inserted describing the animation and how it would be used.

6.1 Selection of the Sample Chapter

The sample chapter was intended to serve two purposes. One purpose was to provide a “straw man” example for review as model *HFG* chapter. This chapter is expected to be subjected to broad external review and critiqued for format, content, style, appropriate depth of treatment, additional features, and so forth. It is a step in the process of evolving the *HFG*. The ultimate version of this chapter might look quite different. The second purpose was to provide a useful, stand-alone product on the topic of the sample chapter. Quite aside from its role as a model for the *HFG*, the effort in producing this chapter should produce a technical work that is of current use to the field.

Both of these considerations were given weight in the process of selecting the sample chapter. However, the two goals were not entirely compatible. Since the *HFG* is viewed as an electronic document consisting of a highly integrated collection of interrelated chapters, with extensive cross-linking, a “stand alone” chapter is not fully consistent with that vision. Furthermore, some topics may function well as typical model chapters but not serve well as independent documents. Other topics may function well on their own but not be very typical of most *HFG* guidance chapters. Some topics may be of particularly strong interest for application, but are very complex and thus are not good first models; others may be relatively straight-forward, but of more limited appeal.

An extensive process of outside review and opinion was provided to the project team for purposes of sample chapter selection. The intent was to have the sample chapter selection reflect the interests and opinions of the various outside parties interested in the development of the document, in addition to those of the NCHRP project panel and the project team. The issue was presented to the NCHRP project panel, the TRB Joint Subcommittee for Development of International Human Factors Guidelines for Road Systems, TRB technical committees with related interests, and others concerned with the *HFG*. The issue was discussed as an agenda item at open meetings of the Joint Subcommittee during the TRB Annual Meetings, preliminarily in January 2003 and further in January 2004. In addition, a presentation was made at the October 2003 Annual Meeting of the Human Factors and Ergonomics Society.

There was a wide variety of opinion on the sample chapter with little initial agreement. Some favored a basic chapter on fundamental human factors principles or data (a Part II chapter) as a useful stand-alone product and logical first step; however, this would have minimal relevance as a model for typical guidance chapters (Parts III and IV). Some favored the choice of a relatively simple and conscribed (in human factors terms) guidance chapter, such as one on rail-highway grade crossings. This was seen as having manageable scope, well-delineated human factors issues, and less dependency on cross-referencing than some other chapters might require. Others favored selecting a chapter on particularly significant safety problems, such as intersections. This would be a complex chapter to develop as a first step, and might interrelate to other chapters in a substantial way. Finally, some recommended the chapter on sight distance (time and speed). It has the virtue of dealing with key concepts that will relate to subsequent chapters, yet (unlike sections in Part II) provides specific guideline statements. However, these guidelines are likely to be at a more general level than for other chapters that are more specific to a roadway location element (e.g., curve, intersection) or traffic engineering element (e.g., signing). The sight distance chapter is in some ways a bridge between Part II and Part III of the *HFG*.

After considerable discussion, a general recommendation emerged from the panel and Joint Subcommittee that the sight distance chapter be selected. While there was not complete consensus, this appeared to be the most agreeable choice and was also reasonable to the project team. Although it is not entirely typical as a guidance chapter, it does serve as an example of guidance and at the same time provides a topic that can be the basis of a useful stand-alone document. Therefore Chapter 5, “From Driver Reaction

Time, Maneuver Time, and Speed to Design Distances: General Guidelines," is the chapter that was developed. This represents an important human factors topic for traffic engineering and roadway design and is at a general enough level to serve as a useful stand-alone document. However, it should be kept in mind that this chapter is not likely to be typical of subsequent chapters in terms of the specificity of the applications.

6.2 Introductory Chapter (Chapter 1. Why Have Human Factors Guidelines for Road Systems?)

Chapter 1 explains the need for human factors guidelines and the purposes for which the document is intended. It is an intentionally brief chapter that is meant to convey that there is something useful for the designer/engineer here. This introductory chapter does not contain guidance or technical detail. Part II of the *HFG* will contain the more extended discussion of human factors concepts, data, and principles, while Parts III and IV will provide the explicit guidelines. This chapter is envisioned as one of two chapters that comprise Part I of the *HFG*. It is comprised of three general sections:

- What is Human Factors?
- Why are Human Factors Guidelines for Road Systems Necessary?
- Purposes of This Document

The other complementary chapter in Part I will be "Chapter 2: How to Use This Document." It will deal more with the mechanics of how to use the document and the guidelines. Chapter 2 will need to be written as the *HFG* develops and expands beyond a single sample chapter and has actual search and linking capabilities. It will describe the content and organization of the document, the format of the background and guidance sections, search capabilities, relationship to and use with other standards/guidelines, and reference documents, and links to related resources. Chapter 1, then, succinctly defines the field, scope, need for, and function of the document.

Because the primary (though not sole) purpose of the *HFG* is provide guidance for practicing traffic engineers and highway designers, the introductory chapter must address possible lack of knowledge and misconceptions from readers who are not well-versed in human factors. While Part II of the *HFG* provides more full explanation regarding the field, Chapter 1 must overcome these barriers to appreciation of the relevance of the document. Among the concerns that must be explicitly addressed are:

- The scientific nature of the discipline of human factors and how it directly relates to traffic engineering/road design issues
- What human factors brings that is unique and complementary to existing practice
- The misperception that driver behavior and human factors considerations are already fully and adequately incorporated into design standards
- The difference in the perspectives of ordinary road users and those of road designers/traffic engineers and why this matters

The introduction must also portray the *HFG* as a useful and usable supplement to the resources that designers and engineers already use. It must be shown to be an aid and not another burden. While all of these issues require some depth of discussion, those more technical expansions are appropriate for Part II of the *HFG*. Chapter 1 provides the opportunity to explain succinctly the purpose of the *HFG* and the reasons why it may be helpful to the practitioner.

6.3 Sample Guidance Chapter (Chapter 5: From Driver Reaction Time, Maneuver Time, and Speed to Design Distances: General Guidelines)

Section 6.1 already discussed the process of the selection of the sample chapter and some of its considerations. The sample chapter is titled "From Driver Reaction Time, Maneuver Time, and Speed to Design Distances: General Guidelines" and is referred to as Chapter 5 of the *HFG*. This chapter deals with sight distances and how they are related to the human behavioral and perceptual aspects of perception-reaction time, maneuver time, and speed. Sight distance is a fundamental design concept, but it is not a *behavioral* one. The human factors is in the behavioral components that generate the design distance requirements. Hence the title of this chapter, which considers the human factors of the component driver processes and how they lead to distance needs. The chapter is referred to as "Chapter 5" based on the *HFG* outline in the November 2002 Task 2 Report for this project. It is recognized that chapter numbers may be different from those in the outline as the document evolves.

This chapter is seen as the first "guidelines" chapter in the *HFG*. It is somewhat unique from subsequent guidance chapters in that it is not specific to a roadway location element (e.g., curves) or traffic engineering element (e.g., signing). The guidance principles are therefore at a somewhat more general level than in subsequent chapters. Design distance issues that are specific to a particular roadway location element or traffic engineering element will be treated in detail in the appropriate chapters. Differences among applications are dealt with here, but within this chapter the emphasis is on principles that are relevant to many design conditions. In this sense, Chapter 5 is something of a bridge chapter between Part II of the *HFG*, which provides basic human factors concepts, findings, and approaches, and Parts III and IV, which provide specific guidance statements for particular applications.

The chapter is comprised of five sections and an appendix. Section 5.1 is a background section that describes the human factors issues and chapter objectives, and indicates how the chapter is related to other key reference documents. Section 5.2 provides the technical treatment and guidance for design sight distance, broken into subheadings that reflect the major sight distance design criteria: stopping sight distance, intersection sight distance, decision sight distance, and passing sight distance. Section 5.3 addresses the influence of design on speed; since speed (V term) is a key element of sight distance design equations, the human factors concerns of speed determinants directly impact sight distance needs. Section 5.4 provides an approach to diagnosing human factors-related sight distance problems. Section 5.5 is the chapter reference citation section. The attachment (Appendix A of the sample chapter) provides an example application of the Section 5.4 diagnostic procedure.

This chapter structure is somewhat different from the original chapter outline (submitted under Task 6 of this project). The original vision of the chapter outline proposed major headings for Perception-Reaction Time (5.2) and Maneuver Time (5.3), and within each of these, subsections for the various types of sight distance. In practice, this turned out to be unwieldy, repetitive, and hard to use. It was more useful to have perception-reaction time, maneuver time, and sight distance as subsections under each sight distance type, rather than sight distance types as subsections under other separate headings. In this way, all of the considerations for a given design application (e.g., stopping sight distance) are in one place.

Because Chapter 5 is intended to serve as a stand-alone document on human factors and sight distance, beyond its "straw man" model chapter role, the introductory section of the chapter is somewhat unusual. This introduction precedes Section 5.1, which is the actual beginning of the chapter itself. The introduction contains background information (parallel to information contained in this report) that explains the purpose and features of the chapter. It explains how this sample chapter may differ somewhat from more typical Part III and IV chapters of the *HFG*. Such an introduction obviously will not be typical of actual *HFG* chapters, but is necessary in Appendix C if the chapter is to function in a stand-alone mode. Also, the chapter contains more extensive introductory discussion than would be anticipated in most chapters, since there are no existing supporting chapters to which links may be made.

7.0 References

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APPENDIX A

HFG WORK PLAN

1.0 Work Plan for Developing the *HFG*

This section provides a work plan for developing the document *Comprehensive Human Factors Guidelines for Road Systems* ("*HFG*"). This work plan was developed under Task 3 of NCHRP Project 17-18(8), Comprehensive Human Factors Guidelines for Road Systems. The purpose of the project was to establish a basis for the subsequent development of a guidance reference document on human factors, for use by highway designers and traffic engineers. The work plan presented here is taken from the project Task 4 report (November 2002), with minor editorial changes.

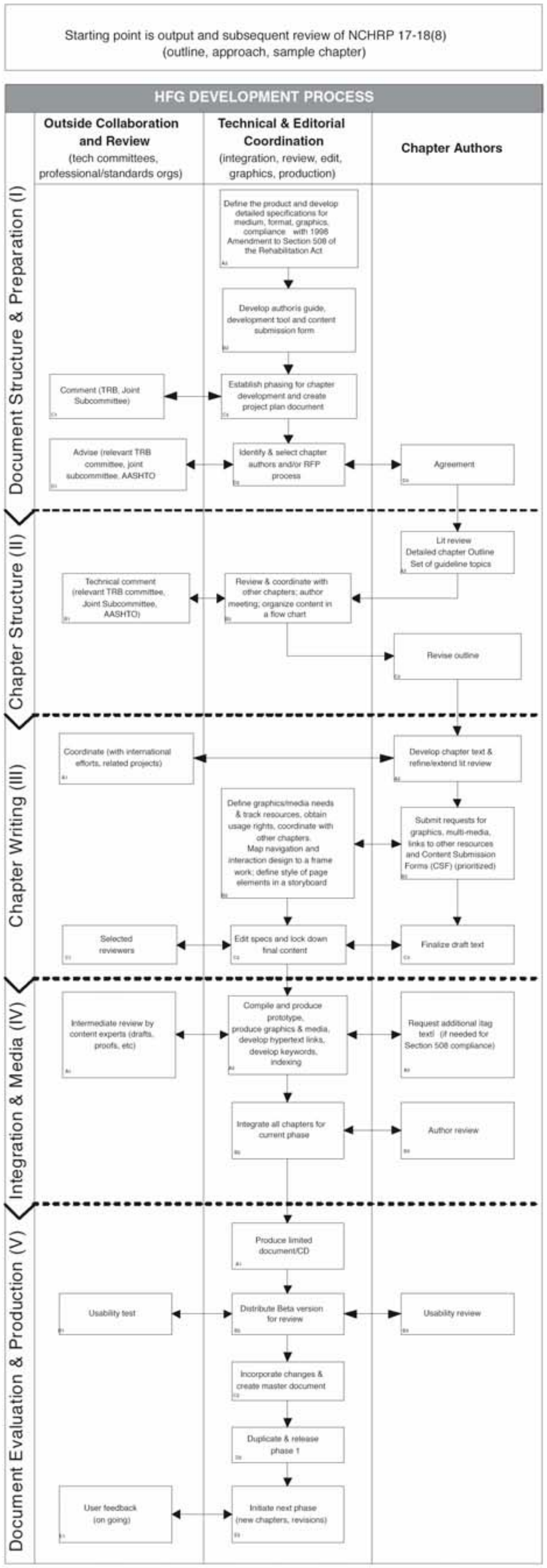
The work plan considers the activities and effort that will be required to develop a first edition of the *HFG*. The plan addresses this in two sections. Section 2.0 deals with the process of document development and is structured around a flow chart of activities. Section 3.0 then provides order-of-magnitude estimates of the level of effort, schedule, and costs involved in working to the plan shown in Section 2.0. These estimates are acknowledged to be very rough and are only for purposes of providing a general sense of the scale of effort.

2.0 Required Activities, Roles, and Outside Interactions

Figure 1 below summarizes the project tasks, internal coordination activities, and cooperation with outside groups that are required in producing the *HFG*. This chart represents the product of several iterations in defining the work structure and it is consistent with the "model" of the *HFG* described in the project Task 2 report. Consistent with that model, the effort is not seen as the production of a set of more-or-less independent chapters. Rather, there is a significant effort to integrate the individual chapter guidelines, both within the document and externally to the key design reference sources. The figure is organized into three columns. The center column shows the activity of the central "Technical and Editorial Coordination" provider. The right column shows the activity of the individual chapter authors. The left column shows the activity of outside reviewers and collaborators at various points in the project. The arrows show the flow of activity between these various entities and from one task to the next. Vertically, the chart shows the sequence of activity (from top to bottom), conceptually divided into five major segments:

I. Document Structure and Preparation
II. Chapter Structure
III. Chapter Writing
IV. Integration and Media
V. Document Evaluation and Production

Figure 1. *HFG* development tasks, internal coordination activities, and external cooperative and review activities



As noted at the top of the figure, the starting point for the work plan begins with the output of NCHRP 17-18(8). That means there will be an outline, general conception of the document and its medium, and a sample chapter. It is expected that the sample chapter that emerges from 17-18(8) will undergo review and critique from a wide range of sources, so that the format may be subject to revision as the plans for the *HFG* are put in place.

The three columns of the chart represent three broad spheres of activity. The coordinating and editing role (center column) is critical to the assumption of an interactive document that links key sections and concepts within the *HFG*. Since the individual chapters must be closely linked and mutually supportive, non-redundant, and supportive of a holistic, or "system," view of roadway safety and driver performance, this central coordinating function is very much part of the "writing" process. The types of experts required under this column include editors and technical writers, content experts in highway safety, multi-media and graphics specialists, illustrators, and programmers.

The right column of the chart shows the activities of the chapter authors. There are two primary written documents. Initially there is a literature review that produces a critical overview of the technical basis underlying the guidelines. Later, there is the *HFG* chapter itself, in a standard format, providing specific guidance. Notice there are various collaborative demands on chapter authors. The chapters will be subject to outside review from the Joint Subcommittee, relevant TRB committees, and others at various points, and chapter authors will have to be responsive to these stakeholders and interested parties. Furthermore, because of the integrated nature of the document, the author's work does not end with submission of the chapter; after that point, the various authors, working with the editorial providers, are kept in the process at specific interaction points as the chapters mutually evolve. It should therefore be recognized that the effort required of chapter authors will be somewhat greater than if they were simply writing stand-alone chapters for a less interactive document. Authors will also have to work collaboratively with the editorial coordinators to develop appropriate graphics and animations. The assumption is that planning, designing, and programming illustrations, animations, video, etc. will housed with the technical and editorial function, and not the responsibility of the chapter author. The chapter author proposes the graphics and multimedia features, and the editorial group coordinates and executes them.

The left column of the figure shows the outside collaboration and review. As the figure makes evident, the *HFG* development process is "open" and subject to comment from a variety of sources at a variety of times. The outside review include such groups as TRB technical committees, the Joint Subcommittee, AASHTO, parallel projects (especially European efforts also growing out of the Joint Subcommittee), expert reviewers, and potential *HFG* users.

Moving vertically down the chart, the five major activities are shown. Within each, the boxes of the flow diagram show the specific tasks to be done by the coordinators, authors, and reviewers. The arrows show the flow of activity and information between tasks and entities. The initial set of tasks (Document Structure and Preparation) provide the basis for everything that needs to be done prior to the chapter authors actually starting their work. This includes detailed functional specifications and authors guides, phasing and coordination plans, selection of chapter authors, and putting in place of formal agreements. The workplan does not specify precisely how authors will be selected. For example, it could be through competitive procurements or it might be through selection of invited authors. This selection could be done by TRB via NCHRP, by TRB committees, by whatever organization has "ownership" of the *HFG*, or by the organization that holds the technical and editorial coordination role. However this is done, the work plan shows that it is important to include outside advice from key organizations and stakeholders

The second major set of tasks is labeled Chapter Structure. It is under this activity that the chapter authors conduct their literature reviews, develop an outline of their *HFG* chapter, and indicate the set of specific guideline topics they foresee within the chapter. At this point, the chapter authors then must work collaboratively with the editorial coordinator and the other authors, in order to make sure that the individual chapters function together in a complementary manner and are not redundant.

The third set of activities in the chart comprise Chapter Writing. The individual *HFG* chapters are written, reviewed, and revised. Needs for illustrations and multimedia are generated and coordinated, and story boarding of the layout and development of the multimedia components is done. Appropriate permissions for re-publishing figures and graphics are obtained.

In the Integration and Media stage, major central editing activities take place. Graphics and media are developed. Prototype chapters are produced. Integration and editing of all of the chapters is done. Hypertext links and keyword indexing are done. During this work, outside experts will review the individual chapters. Individual authors will review the integrated document. This provides them an opportunity to make sure that the interactive aspects and relation of their chapter to other chapters is appropriate. It also allows them to see and comment on any other editorial changes made to their sections.

The final phase is document evaluation and production. A Beta version of the *HFG* is produced and subjected to usability testing. We feel that it is very important that typical users (rather than content experts) try working with the *HFG* before it is finalized. Any changes required based on usability testing or author review will be incorporated into the master document, which can then be duplicated and released. At the bottom of the chart, we have tried to show that there should be some ongoing process for getting user feedback and improving the *HFG*.

One unresolved issue at this point is the phased nature of developing the *HFG*. As envisioned, the *HFG* will have 21 chapters when the first edition is complete. Because of the extensive editorial and technical coordination required, as well as outside review, it would be most efficient if all of the chapters were written and integrated at the same time. However, given the scale of this effort, resources likely will not be available to do everything in one effort. Therefore, development of the *HFG* will have to be phased.

The more chapters per phase, and fewer phases, required, the more efficient the development process will be. Also, the more chapters developed in the initial phase, the more useable the first phase *HFG* will be, given the linking between chapters.

3.0 Estimated Effort and Time

In order to generate some initial estimates of effort and time, we had to make some assumptions about the phasing of *HFG* development. As noted just above, developing all of the chapters at one time would be most efficient, but is unlikely. The working assumption for the estimates of effort was that the first edition of the *HFG* would be accomplished in three phases, each comprised of about six technical chapters.

Table 1 provides a breakdown of the estimated level of effort for various categories of personnel. The tasks shown in the table correspond to the various rows of boxes in Figure 1. For example, in the first work phase of the figure (Document Structure and Preparation), there are five rows of boxes. The first row is labeled IA (first row of part I), and the subsequent rows IB, IC, ID, and IE. Each of these corresponds to a row in Table 1. The entries in the table show the number of estimated hours of effort associated with each task for each category of personnel. Note that in this table, the hours shown for chapter authors (Senior Author and Junior Author) correspond to the effort required <u>for each chapter</u>. Therefore, if it is assumed that six chapters are being written in a given phase of *HFG* development, the author estimates must be multiplied by six to get an estimate of the total level of author effort across all the chapters being developed. Note that the total author hours include literature review and write-up, development of guidelines, writing of the *HFG* chapter, periodic reviews of one's own and the full set of chapters, collaboration and coordination for internal and external reviews, and review/exercising of the final CD-ROM-based *HFG*.

PERSONNEL / TASK	Project Manager	Sr Highway Safety Expert	Jr Highway Safety Expert	Admin Support	Sr Editor	Jr Editor	Book Publishing Copyright Expert	Sr. Programmer	Jr. Programmer	Multi-media/Graphics Coordinator	Instructional Designer	Sr Multi-media Designer	Multi-media Author	Animator / Illustrator	Print / Duplication Coordinator	Sr. Author	Jr. Author
DOCUMENT STRUCTURE & PREPARATION (I)																	
Task I																	
A	40	30		24	24	24				24		24	12				
B	40	20	20	24	24	20				24		20	12				
C	16			4	16	16											
D	8	8		4													
Total	104	58	20	56	64	60	0	0	0	48	0	44	24	0	0	0	0
CHAPTER STRUCTURE (II)																	
Task II																	
A																150	150
B	24	40	20	16	40	40				24			24			30	30
C																	
Total	24	40	20	16	40	40	0	0	0	24	0	0	24	0	0	180	180
CHAPTER WRITING (III)																	
Task III																	
A																160	150
B	60	40	24	40	80	80	40			120	120	168	325			20	40
C	8	8		8	32	20										40	40
Total	68	48	24	48	112	100	40	0	0	120	120	168	325	0	0	220	230
INTEGRATION & MEDIA (IV)																	
Task IV																	
A	60	40	40	40	80	80		200	200	100	80	1280	484	1640		36	40
B	40	20	20	20	60	60		40	40	24	32	320	96			40	24
Total	100	60	60	60	140	140	0	240	240	124	112	1600	580	1640	0	76	64
DOCUMENT EVALUATION & PRODUCTION (V)																	
Task V																	
A	20			24	30		20	20	20	8		44	20		20		
B	20	20	20	24	10					12					20	24	24
C	40	40	40	24	80	80		40	40	12		100	40				
D	40			24	40	20	20	10	10	8					40		
E										8							
Total	120	60	60	96	160	100	40	70	70	48	0	144	60	0	80	24	24
TOTAL	416	266	184	276	516	440	80	310	310	364	232	1956	1013	1640	80	500	498

Table 1. Personnel Category Level of Effort by Task.
(note: "author" columns show per chapter estimates)

Table 2 uses the level of effort estimates to generate order of magnitude costs for developing the *HFG*. Again, the costs will be reduced as the number of chapters done at one time is increased, since the editorial and technical review process will be more efficient. The table uses an approximate "loaded" hourly labor rate for each category of personnel. This should be taken only as a crude figure to help generate the rough order of magnitude estimate. The top portion of Table 2 shows the "rolled up" hours from Table 1, and the lower portion applies the hourly rates to derive costs. Total cost roll-ups are shown for both Tasks and Personnel. As noted, the assumption in Table 2 is that about six technical chapters are being developed. The cost of developing all 21 chapters is therefore roughly about three times this value.

PERSONNEL	Project Manager	Sr Highway Safety Expert	Jr Highway Safety Expert	Admin Support	Sr Editor	Jr Editor	Book Publishing Copyright Expert	Sr. Programmer	Jr. Programmer	Multi-media/Graphics Coordinator	Instructional Designer	Sr Multi-media Designer	Multi-media Author	Animator / Illustrator	Print / Duplication Coordinator	Sr. Author	Jr. Author	
Rate	130	130	90	45	130	90	130	130	90	130	90	90	55	90	90	130	90	
Task Hours																		**Total**
I	104	58	20	56	64	60	0	0	0	48	0	44	24	0	0	0	0	478
II	24	40	20	16	40	40	0	0	0	24	0	0	24	0	0	1080	1080	2388
III	68	48	24	48	112	100	40	0	0	120	120	168	325	0	0	1320	1380	3873
IV (low)										64	16	800	320	200				
IV(high)	100	60	60	60	140	140	0	240	240	60	16	800	260	1440	0	456	384	4456
V	120	60	60	96	160	100	40	70	70	48	0	144	60	0	80	144	144	1396
Total Hours	416	266	184	276	516	440	80	310	310	364	152	1956	1013	1640	80	3000	2988	13991
Task Cost																		**Total**
I	13520	7540	1800	2520	8320	5400	0	0	0	6240	0	3960	1320	0	0	0	0	50620
II	3120	5200	1800	720	5200	3600	0	0	0	3120	0	0	1320	0	0	140400	97200	261680
III	8840	6240	2160	2160	14560	9000	5200	0	0	15600	10800	15120	17875	0	0	171600	124200	403355
IV	13000	7800	5400	2700	18200	12600	0	31200	21600	7800	1440	72000	14300	129600	0	59280	34560	431480
V	15600	7800	5400	4320	20800	9000	5200	9100	6300	6240	0	12960	3300	0	7200	18720	12960	144900
Total Cost	54080	34580	16560	12420	67080	39600	10400	40300	27900	39000	12240	104040	38115	129600	7200	390000	268920	1292035

Per chapter cost of authors = 109820

Break out of IV						TOTAL
Low (4 chapters)	64	16	800	320	200	**1400**
High (2 chapters)	60	16	800	260	1440	**2576**
TOTAL	**124**	**32**	**1600**	**580**	**1640**	

50 - 10 plain illustratior
720 - 2 min. animation

Table 2. Hours and Costs for Initial *HFG* Development (6 chapters)

Some points in Table 2 bear mention. First, a critical assumption is the extent to which this CD ROM-based document makes use of multimedia capabilities. By these we mean illustrations, animations, video clips, and interactive capabilities. These features require meaningful effort from multi-media and graphics specialists, illustrators, and programmers. The assumption in the cost breakout is that among the six chapters, four have “low” multimedia requirements and two have “high” multimedia requirements.

A second point is to note that the per chapter author costs are about $110K. As noted above, these costs cover both a senior and supporting junior author for tasks including literature review and write-up, development of guidelines, writing of the *HFG* chapter, periodic reviews of one’s own and the full set of chapters, collaboration and coordination for internal and external reviews, and review/exercising of the final CD-ROM-based *HFG*. As a reasonableness check on this “bottom up” derivation of cost, we approached from another perspective. TRB periodically funds development of synthesis papers on various topics. We see this as roughly analogous to the literature review and interpretation phase of the *HFG* author’s task. These TRB syntheses are generally funded at about $40K. Following this synthesis, we see the subsequent actual development of guidelines and the writing of a complete chapter, including re-writes after the various points of interaction with all of the interested outside parties, as a slightly larger task than the initial literature review. Therefore we used a rough estimate of $50K for this phase. Finally, the integrative and interactive nature of the *HFG* places a burden of working interactively with the central editors and with other authors, including reviews of others work, development of graphics, evaluation, etc. We estimated these technical and administrative tasks to require roughly $20K of effort over the period of the entire project, from conception through Beta testing and final release. Summing these three gross estimates ($40K, $50K, $20K), the total is $110K. Thus this figure seems to be at least roughly of the right magnitude, given all that the authors are presumed to do. We recognize that this is higher than the typical cost of authoring something like a book chapter. However, the conception of a CD ROM based interactive document as a support tool, rather than a simple text document, results in many more requirements. Also, as laid out in the plan, each author is developing two documents: the guidelines chapter for the *HFG*, and the detailed supporting literature synthesis.

A final point to note about the cost breakout is that the estimated costs of chapter authors represents a little over half of the total costs. The requirements for technical content expertise and editorial efforts of the coordinating entity are substantial and the assumed degree of effort in animation, illustration, and other multi-media requirements is even greater. Again, this stems from the integrative and multi-media character of the *HFG*. At the same time, the project team acknowledges that these are very crude order of magnitude estimates and that other assumptions could lead to different estimates. In generating the initial estimate, we included in the discussions experts in the various disciplines associated with the presumed process.

The period required to perform this work (initial set of chapters) is estimated at about 18 months. This includes time for outside review, although the turn-around on review can sometimes be more extended. The estimate of 18 months is based on the assumption of:

Task I	2.0 months
Task II	4.0 months
Task III	6.0 months
Task IV	3.5 months
Task V	2.5 months

APPENDIX B

HUMAN FACTORS GUIDELINES FOR ROAD SYSTEMS

DRAFT INTRODUCTORY CHAPTER

CHAPTER 1
WHY HAVE HUMAN FACTORS GUIDELINES FOR ROAD SYSTEMS?

TABLE OF CONTENTS

1.1 Overview of *Human Factors Guidelines for Road Systems: Design and Operational Considerations for the Road User*

Human Factors Guidelines for Road Systems: Design and Operational Considerations for the Road User is a guidance document that brings human factors principles and findings to the highway designer and traffic engineer. It will allow the non-expert in human factors to more effectively bring consideration of the roadway user into practice about design, operations, and safety. The *Human Factors Guidelines* serves as a complement to other primary design references and standards. It does not duplicate or replace them. It is an additional tool for the engineer to use in designing and operating roadways that are safe and efficient – roadways that are safely usable by the broad range of roadway users.

The document is divided into four parts. "Part I: Introduction to the *Human Factors Guidelines*," is a short introduction to the document. This first chapter explains why it is useful to have such guidance. The second chapter explains how to use the document and take advantage of its features.

"Part II: Bringing Road User Capabilities Into Highway Design and Traffic Engineering Practice" describes a human factors approach to roadway design, presents basic principles and methods, and provides key information about basic road user capabilities. Part II is about road users and how to take their needs into account. It is the basis from which the guidance in Parts III and IV is derived.

Parts III and IV present the actual guidance statements within this document. "Part III: Human Factors Guidance for Roadway Location Elements" is organized around specific roadway location elements, such as signalized intersections and work zones. "Part IV: Human Factors Guidance for Traffic Engineering Elements" deals with traffic engineering elements such as fixed signage, variable message signs, markings, and lighting. The guidance among many of these chapters is interrelated and the chapter sections link to one another. Chapter 2 (in Part I) explains how the guidance chapters are organized and how they can be searched and used.

1.2 What is "Human Factors?"

1.2.1 The Discipline of Human Factors and Its Relation to Traffic Engineering

Application of good human factors principles, in useful guideline form for the practitioners who design and operate streets and highways, is fundamental to the safety of all road users. The ITE *Traffic Engineering Handbook* (Pline, 1999) cites a definition of "traffic engineering" as "that branch of engineering which applies technology, science, and human factors to the planning, design, operations and management of roads, streets, bikeways, highways, their networks, terminals, and abutting lands." Thus the discipline of human factors is recognized as an integral contributor traffic engineering practice. However, many highway designers and traffic engineers do not have a clear understanding of what human factors is and how its principles are relevant to their work.

Human factors is the scientific discipline that studies how people interact with devices, products, and systems. It is an applied field where behavioral science, engineering, and other disciplines come together to develop the principles that help assure that devices and systems are usable by the people who are meant to use them. The field approaches design with the "user" as its focal point. Human factors practitioners bring expert knowledge concerning the characteristics of human beings that are important for the design of devices and systems of many kinds. The discipline contributes to endeavors as complex as space exploration and to products as simple as a toothbrush. In the field of transportation engineering, there have been numerous important contributions from human factors, but these are not always self-evident. Sight distance requirements, workzone layouts, sign placement and spacing criteria, dimensions for road markings, color specifications, sign letter fonts and icons, signal timing – these and many more standards and practices have been shaped by human factors evaluation.

As applied to highway safety, human factors is concerned with the design of the roadway and operating environment and the vehicle. The three primary components of the highway transportation system – the roadway, the vehicle, and the road user – all must be compatible with one another. Engineers can design roadways, traffic control devices, and vehicles, but they cannot design the road user. They can design *for* the road user. Human factors provides an objective basis for doing this. It is based on measured behavior and capabilities rather than assumptions or trial-and-error.

Of course, roadways have been designed for many years while the science of human factors was still maturing as a discipline that could provide reliable contributions. The needs and abilities of road users were not ignored, but they were not fully and systematically included either. Fortunately, the human being is very adaptable. That is why over history, complex man-made systems have been able to evolve and work reasonably well, even though inadequate consideration was given to the needs of the human user. The transportation system in general, and the highway system in particular, certainly provide good examples of this. One cannot deny the success of modern traffic engineering practice. In the U.S. in 2001, nearly 200 million drivers of extremely varying capabilities shared the roadways while logging almost three trillion travel miles in relative safety and efficiency (NHTSA, 2002). In many cases, this is because the road user is able to adapt to the demands of the driving environment, not because the driving environment has been adapted to the user. At the same time as we acknowledge the successes of the system, we must also recognize its limitations. In 2001, there were over six million police-reported (and many more non-reported) collisions in the U.S., with attendant loss of life, property, and productivity (NHTSA, 2002). Some form of operator error is often a contributing factor in highway crashes. "Error" means the road user did not perform his or her task optimally. Misperceptions, slow reactions, and poor decisions are the products of a poor match between the needs and capabilities of drivers and the task demands that they face on the roadway. A more driver-centered approach to highway design and operation will promote continued improvements in highway safety. There has been greater and greater awareness and acceptance of this insight over recent years.

Traffic engineering practice certainly did not develop ignoring the driver. But systematic data on driver capabilities and performance as a resource for design practice is relatively recent. The body of what we now label "human factors" research began in the 1950s (primarily in the area of highway sign design) but really began to advance meaningfully only in the 1960s, long after many standards and practices were established. Roadway user human factors research accelerated over the next decades. This ever-growing body of knowledge has gradually made inroads into design and practice. However, a user-centered perspective is still not characteristic for many practitioners. In part, this is because the now large body of knowledge regarding the roadway user is not easily usable. It is not organized, summarized, explained, and made accessible to the engineer. It is not tied in a useful way to the everyday tools and resources used by the engineer.

1.2.2 Hallmarks of the Human Factors Approach

There are some important fundamental principles that characterize the human factors approach to designing things. These characteristics are compatible with the goals of highway designers and traffic engineers and help explain why human factors practice so successfully complements traditional traffic engineering approaches. Part II of this document explains these distinguishing qualities and how they contribute to highway design and operational practice. Briefly, some of the most important hallmarks of the human factors approach are these:

- <u>User-centered design</u>. The human factors approach to design begins with understanding the task to be accomplished, from the user's point of view. A "task" may be something like avoiding an obstacle, selecting an appropriate path for the vehicle, or deciding whether to accept a gap to make a maneuver. The analysis then examines what information the user needs to accomplish the task and considers this along with the capabilities, knowledge, and motivations of the range of potential users. When the design of a device or system is consistent with the characteristics and needs of the user, performance is more rapid and reliable and less prone to error.
- <u>Empirically-based science</u>. Human factors is based on a scientific approach with empirical measurement at its core. It is not a "soft" discipline of a speculative nature. Wherever possible, it is based on empirical measurement of human capabilities and behavior in relation to engineering design, collected under rigorously controlled conditions, including laboratory, driving simulator, traffic observational, and instrumented vehicle studies. Human factors brings to traffic engineering both an empirical base of fundamental human capabilities and specific data on driver behavior under various conditions.
- <u>Systems perspective</u>. A highway designer or traffic engineer may deal with one element at a time, for example the design or delineation of a roadway curve. But to the roadway user, everything occurs in a broader context, and this can matter very much. Features and events on the road seldom appear as isolated events. The road user is dealing with multiple concerns at any moment and is influenced by preceding events, anticipated events, multiple sources of information, and competing demands. The human factors scientist seeks to understand how people

are likely to behave when they encounter the designed element in its real-world context.

- Focus on behavior. The design and traffic engineers are concerned with the performance of the *highway system* – operational efficiency and safety. Human factors specialists are concerned with the *behavior of road users*, which is among the important determinants of highway system performance. Human behavior is rarely simple and people can vary greatly from one another. Therefore the human factors field must deal with the range and complexity of road user capabilities and behaviors in relation to engineering design.
- Life-cycle application. Human factors can and should contribute to the design and operation of a device or system throughout the product life cycle. This means that human factors concerns enter into initial planning, design, construction, operation, evaluation, and maintenance. The earlier in the process human factors considerations are dealt with, the more beneficial it may be.

This brief overview should help clarify what "human factors" means and how it contributes to the goals of the roadway designer and traffic engineer. Part II of this document provides a much richer discussion and more examples.

1.3 Why are Human Factors Guidelines for Road Systems Necessary?

Why is it necessary to have a document on "human factors guidelines for road systems?" Even granting the importance of roadway user characteristics, isn't this already incorporated into the basic standards and guidelines for highway design and traffic engineering? It might seem that the human factors considerations ought to be transparent to practitioners. The human factors components that contribute to design equations and operational parameters do not have to be understood in order to follow standard practice. However, there are some important reasons why the highway designer or traffic engineer needs to be aware of key human factors concerns. It is not necessary for them to become human factors experts, but it is important to be able to think in human factors terms and have access to human factors data and methods. Some reasons why guidance on human factors is required for road system design and operations are listed below.

1.3.1 Limitations of humans factors incorporated into standards and guidelines

Some practitioners have the misperception that human factors are fully and adequately considered and integrated into current standards and guidelines. Although some practices are based on extensive, well-documented, and fully appropriate behavioral data, this is certainly not always the case. Existing standards and guidance include the following limitations:

- Many practices do not have any empirical basis. They were not developed based on data to begin with and have not been formally evaluated for adequacy for road users.
- Some practices are based on outdated or inadequate behavioral data. While some practice may have been justified based on limited observations made forty years ago, the measured behavior may no longer be representative of current behavior,

given changes over the years in roadways, vehicles, traffic, operations, and even drivers.

- Both the roadway system and human behavior are complex and there may be some applications where a minimum design requirement is insufficient to support the desired driver behavior.
- Some practices are based on simple models of what road users see or do. These models may work well for most cases but may over-simplify other situations.
- Design equations are based on certain operational and user behavior assumptions and these assumptions are not always met.
- Technology and operations are constantly evolving. Design decisions have to be appropriate to current and emerging environments and options. Standards and guidelines may not keep pace with changes in communications technology, vehicle features, roadway features, roadside environment, traffic control devices, or traffic operational characteristics.
- There may be particular human factors concerns for special user groups and these concerns may have prominence for certain applications. With the aging of the general population, there has become much greater concern with older road users, although their needs are not fully reflected in standards and practice. Examples of other road user groups of emerging importance include visually impaired pedestrians, pedestrians with mobility limitations, heavy truck operators, and users of lower-speed alternative transportation devices.
- Under real-world conditions, there may be cases where it is not possible to meet certain specifications or where there is a requirement for a trade-off between two or more conflicting demands. The impacts on user behavior must be carefully considered.
- There may not be standards or guidance to deal with particular combinations of features that may impact human performance.

For these reasons, it is unwarranted simply to assume that current practice already takes adequate consideration of human factors concerns for all situations. With appreciation and guidance on human factors issues, the practitioner can better recognize where additional user-centered design concerns arise.

1.3.2 Meeting road user system needs

Those who design and operate the roads need to be able to see the situation from the perspective of the roadway users who must use their products. Road users are not narrowly focused on some particular roadway element or design feature. Rather, they are influenced by all of the factors present at a site, as well as broader features of the roadway network and by features and events leading up to the site. Unfortunately, it is often difficult for a practitioner to acquire this "big picture." The highway design and traffic engineering community is becoming increasingly specialized, with different trades or specialties (lighting, traffic control devices, signing, landscaping, etc.) providing specific contributions at various phases of the design and development process. These interests may be brought in at various stages of design to manage different aspects. This diffusion of responsibilities makes it difficult for the various contributors to fully appreciate the needs of road users as they confront the situation in its full context. A document that provides human factors principles and guidelines will help highway designers and traffic engineers to evaluate their efforts in a more appropriate and more complete context.

1.3.3 Understanding and addressing when human factors problems occur

If a safety or operational problem arises, is it due to a human factors problem? Is there a human factors approach to rectifying the problem? The *Human Factors Guidelines for Road Systems* can help answer these questions. The extensive use of linking among sections and chapters of this document (see Chapter 2) allows the engineer to find the guidance, principles, and data that will help clarify and address the human factors issues. The guidance can also serve as a complement to other sources of diagnostic tools and techniques, such as safety audits or the *Highway Safety Manual* (Hughes, Eccles, Harwood, Potts, and Hauer, 2004).

In summary, there are important reasons why highway designers and traffic engineers need access to human factors guidance. It is not warranted to simply assume good human factors is incorporated into every design practice for every situation or that current guidance adequately covers all applications. The user-centered approach of human factors emphasizes that devices and systems are always designed *for* someone, and the system is improved when the design and traffic engineer understand and encompass the needs and abilities of the range of users.

1.4 Purposes That This Document Serves

The *Human Factors Guidelines for Road Systems* is intended to serve a number of important purposes. There are also some things this document is <u>not</u> meant to be and the reader should not expect.

1.4.1 Uses of This Document

- The *Human Factors Guidelines for Road Systems* provides an introduction to the field of human factors as it is applied to highway design and traffic engineering. It presents the basic concepts and methods and provides fundamentals of road user behavior. It summarizes key data on basic road user capabilities, such as visual acuity, response time, and the distribution of visual attention.
- The *Human Factors Guidelines for Road Systems* provides guidance for more optimal design of highways and traffic control devices. This guidance helps indicate when, where, and how user-based considerations may offer design criteria that may be more effective than minimal design values or typical practice.
- The *Human Factors Guidelines for Road Systems* links human factors data and analysis with related guidance in other key highway design and traffic engineering reference documents. This will help the user in critically assessing the suitability of recommendations, minimum specifications, or options in other documents.
- The *Human Factors Guidelines for Road Systems* provides help in problem solving. When faced with a problem that may be related to road user

considerations, the guidance can help identify probable human factors causes or countermeasures. The document is constructed so that links among chapters and sections help the reader connect related issues, provide key background information when needed, and relate site features and traffic engineering elements.

- The *Human Factors Guidelines for Road Systems* provides an objective resource for support and justification in decision making. The guidance, rationale, background, and principles provide a defensible basis for deviating from normal practice when that normal practice is not optimal from a road-user-based, highway safety standpoint.

1.4.2 What This Document is Not

- The *Human Factors Guidelines for Road Systems* is not an alternative to primary design references in highway design and traffic engineering. It is intended to complement and amplify aspects of these other references, such as *the Manual on Uniform Traffic Control Devices*, the AASHTO *A Policy on Geometric Design of Highways and Streets*, the *Traffic Control Devices Handbook*, the *Highway Safety Manual*, and other guidance. As a supplement, it is not intended to provide comprehensive design specifications or be redundant with the treatment of other documents. The *Human Factors Guidelines for Road Systems* is meant to add to, and refine, existing guidance.
- The *Human Factors Guidelines for Road Systems* is not a textbook or tutorial on human factors or a comprehensive source of human factors literature. It is primarily a source of guidance with technical backup and explanation. It does serve an educational purpose, in that Part II (Bringing Road User Capabilities Into Highway Design and Traffic Engineering Practice) in particular informs the non-expert about human factors perspectives, methods, theory, and data. However, many users of the document may make use of the guidance without ever fully reading Part II. There already exist a number of detailed books and courses on the role of human factors in highway design and safety. The educational function of the *Human Factors Guidelines* is a limited one and it is not intended to create experts in the field of human factors.
- The *Human Factors Guidelines for Road Systems* is not a guide to crash investigation or a comprehensive reference for safety diagnosis. Its content may certainly aid in interpreting crashes and safety/operational problems, but it is not a manual for that purpose and it is specifically focused on human factors, not the fully array of potentially contributing causes. However, various chapters of this document do contain recommended diagnostic approaches for dealing with specific human factors problems.

1.5 References

Hughes, W., Eccles, K., Harwood, D., Potts, I., and Hauer, E. (2004). *Development of a Highway Safety Manual*. NCHRP Web Document 62: Project 17-18(4): Contractor's Final Report. Transportation Research Board, Washington, DC.

NHTSA (2002). *Traffic Safety Facts 2001: A Compilation of Motor Vehicle Crash Data from the Fatality Analysis Reporting System and the General Estimates System*. National Highway Traffic Safety Administration, Washington, DC.

Pline, J. (Editor) (1999). *Traffic Engineering Handbook*. Institute of Transportation Engineers, Washington, DC.

APPENDIX C

HUMAN FACTORS GUIDELINES FOR ROAD SYSTEMS: DESIGN AND OPERATIONAL CONSIDERATIONS FOR THE ROAD USER

DRAFT EXAMPLE CHAPTER

CHAPTER 5

From Driver Reaction Time, Maneuver Time, and Speed to Design Distances: General Guidelines

TABLE OF CONTENTS

5. From Driver Reaction Time, Maneuver Time, and Speed to Design Distances: General Guidelines

This section of the document, preceding Section 5.1, provides an introduction to a draft sample chapter of the Human Factors Guidelines ("HFG"). It provides some information on what the sample chapter is intended to do and on how this document differs in some respects from what might be seen in a typical HFG chapter. This introductory section would not be present in an actual chapter. The actual sample chapter text begins with Section 5.1.

This chapter addresses the human factors basis of sight distance requirements. It is written as a model chapter of a planned document tentatively titled *Human Factors Guidelines for Road Systems: Design and Operational Considerations for the Road User* ("HFG"). Table 1 presents a tentative high-level outline of the HFG, developed earlier in this project (Lerner, Llaneras, Hanscom, Smiley, Neuman, and Antonucci, 2002). As the table indicates, the HFG is comprised of four Parts. Part I is introductory. Part II presents basic human factors concepts and the user-centered design approach. It provides information and data on basic driver capabilities. The concepts, principles, and data in Part II will be related to many of the subsequent guideline statements in the HFG. Parts III and IV are the guidelines sections. Part III provides human factors guidance for roadway location elements, such as curves, transition zones, or intersections. Part IV provides human factors guidance for traffic engineering elements, such as signs, markings, and lighting. The present document corresponds to Chapter 5 of the tentative outline, which is in Part III.

This document has two general purposes:

- It is intended to serve as a model for subsequent chapters of the HFG.
- It is intended to serve as a stand-alone document that provides guidance to the highway designer and traffic engineer regarding human factors considerations for sight distance.

These objectives are somewhat incompatible, in that the HFG is viewed as an electronic document consisting of a highly integrated collection of interrelated chapters, with extensive cross-linking (Lerner et al., 2002). Development of the HFG is planned as a long-term incremental effort involving multiple authors, with input and review from a wide range of technical experts and stakeholders.

Chapters in some sections of the HFG (Parts III and IV) will be highly focused on explicit guidance statements. Other chapters (Part II) provide general principles, explain basic concepts, or describe basic human factors data and procedures for highway safety. Because of the extensive linking, individual chapters of the HFG are not viewed as "stand alone" documents; important information will be contained in other sections and the reader can jump to those when desired. So, for example, guidance chapters will be relatively streamlined and focused on guidance statements, with discussion of background information, underlying concepts, supporting findings, and so forth, provided elsewhere, with the links highlighted. Or, some guidance relevant to signing for roadway curves might be located in the chapter on signs, with links in the appropriate places in the chapter on curves. The present document is intended to show what chapters may look like, yet also function as a useful, stand-alone document. For this reason, it has somewhat more background than is likely to be typical in actual guidance chapters (Parts III and IV) of the planned HFG. At the same time, it has some simulated "links" that point to planned chapters that will have more detail. These simulated links are shown in bold brackets **[Section x.x]**. In the actual HFG, there would only be underlining to indicate a hypertext link. There also are links to other key reference documents.

Table 1. Proposed Parts and Chapters for the HFG (from Lerner et al., 2002)

PART I: INTRODUCTION TO THE *HFG*

Chapter 1. Why Have Human Factors Guidelines for Road Systems?
Chapter 2. How to Use This Document

PART II: BRINGING ROAD USER CAPABILITIES INTO HIGHWAY DESIGN AND TRAFFIC ENGINEERING PRACTICE

Chapter 3. A System Approach to Highway Safety: Thinking Like a Road User
Chapter 4. Basic Driver Capabilities

PART III: HUMAN FACTORS GUIDANCE FOR ROADWAY LOCATION ELEMENTS

Chapter 5. From Driver Reaction Time, Maneuver Time, and Speed to Design Distances: General Guidelines
Chapter 6. Curves (Horizontal Alignment)
Chapter 7. Grades (Vertical Alignment)
Chapter 8. Tangent Sections and Roadside (Cross Section)
Chapter 9. Transition Zones Between Varying Road Designs
Chapter 10. Non-Signalized Intersections
Chapter 11. Signalized Intersections
Chapter 12. Interchanges
Chapter 13. Construction and Work Zones
Chapter 14. Rail-Highway Grade Crossings
Chapter 15. Special Considerations for Urban Environments
Chapter 16. Special Considerations for Rural Environments

PART IV: HUMAN FACTORS GUIDANCE FOR TRAFFIC ENGINEERING ELEMENTS

Chapter 17. Signing
Chapter 18. Variable Message Signs
Chapter 19. Markings
Chapter 20. Lighting

The topic of this chapter is also not entirely representative as a model for other guidance chapters. It was selected in part because it can function relatively well as a stand-alone document and because of current interest in the topic. However, it is in some ways unique as a chapter within the HFG. It is seen as the first "guidelines" chapter in the HFG. It differs from subsequent guidance chapters in that it is not specific to a particular roadway location element (e.g., curves) or traffic engineering element (e.g., signing). The guidance principles are therefore at a somewhat more general level than in subsequent chapters. Sight distance issues that are specific to a particular roadway location element or traffic engineering element will be treated in more detail in the appropriate chapters. Some differences among applications are dealt with here, but within this chapter the emphasis is on principles that are relevant to many design conditions. In this sense, Chapter 5 is something of a bridge chapter between Part II of the HFG, which provides basic human factors concepts, findings, and approaches, and Parts III and IV, which provide specific guidance statements for particular applications.

Based on the preliminary outline of the planned HFG, this chapter on sight distance is labeled Chapter 5. Chapter numbering is likely to change as the actual HFG evolves. However, we retained the chapter number for this sample chapter to help place it in context and to use the tentative outline for purposes of the simulated "links."

5.1 Background

5.1.1 Organization of This Chapter

5.1.1.1 STRUCTURE OF THE CHAPTER

This chapter consists of five subsections. Section 5.1 is a background section that explains the scope and content of the chapter, describes fundamental sight distance concepts and their relation to human factors considerations, considers the features and limitations of sight distance design equations as models of driver behavior, and relates the chapter to other key reference sources.

Sections 5.2 and 5.3 provide explicit guideline statements. Section 5.2 is organized around four primary sight distance applications: stopping sight distance, intersection sight distance, decision sight distance, and passing sight distance. For each of these applications there is a section on definition, a set of high-priority considerations, stated guidelines, and a discussion of the basis and rationale for the guideline. The primary focus of Section 5.2 is with the factors that influence perception-reaction time and maneuver time and distance. Section 5.3 deals with the influence of design on speed, as speed relates to sight distance requirements.

Section 5.4 provides a systematic approach for diagnosing and addressing sight distance problems. It is a diagnostic tool that comprises a series of analytic steps. While Sections 5.2 and 5.3 provide guidance in the form of guidelines statements, Section 5.4 is a more procedural way of addressing many of the issues raised in Sections 5.2 and 5.3.

Section 5.5 provides full reference citations for sources cited in the chapter.

5.1.1.2 RELATIONSHIP TO OTHER CHAPTERS

While written as a stand-alone document, this document is also intended to be viewed as a chapter within the HFG. It has an important relationship to other sections of the HFG.

Sight distance will be an important consideration for a number of roadway location elements that are the subjects of specific chapters in Part III of the HFG (see Table 1). We anticipate those chapters will link to the relevant portions of Chapter 5 where general sight distance considerations arise. We also anticipate that these chapters will have more application-specific guidance that goes beyond the general guidance of Chapter 5. The guidelines in Section 5.2 and 5.3 are somewhat limited in specificity because they are meant to be broadly applicable to many applications. Guidance in subsequent chapters of Part III will be narrower and more specific, or link back to Chapter 5. Likewise, Part IV chapters will link to Chapter 5 but will have more specific treatments of the relationship of sight distance issues to their topics.

Speed control is a very fundamental aspect of highway design and traffic engineering and has many related human factors issues. Because vehicle speed is a key element of sight distance requirements, this chapter addresses driver speed selection in this context, most specifically in Section 5.3. Speed control will be treated in some detail for the individual roadway location elements of other Part III chapters (e.g., curves, transition zones, work zones). However, in dealing with driver speed selection in this chapter, it has become evident that there is a need for another cross-cutting chapter that deals with speed in much more detail. Specifically it needs to consider the human factors aspects of speed choice, speed perception, and speed control. No such chapter was proposed in the outline of the HFG (because of treatment within specific Part III chapters and discussion in Chapter 4 of Part II). However, this now appears to be an oversight. In developing this chapter, we saw the need for linking to much more detailed treatment of speed than is appropriate within this chapter. We suggest that a future chapter on driver speed selection and speed management be added to the HFG.

This chapter also relates to the fundamental human factors concepts and driver attributes presented in Part II of the HFG. Issues such as perception-reaction time, driver expectancy, and driver attributes are essential considerations for understanding human factors concerns in sight distance. In the final version of the HFG, it may even be appropriate to move some of the material from this chapter to Part II and treat it through links. However, in order to make this chapter useful as a stand alone document, it contains enough basic human factors considerations to make it self-contained.

5.1.2 The Human Factors Basis of Sight Distance Design Requirements

5.1.2.1 OBJECTIVE OF THIS CHAPTER

This chapter describes human factors considerations that influence sight distance requirements. Sight distance is the length of roadway ahead that is continuously visible to the driver. It is a central concept in roadway design because the driver must have enough preview of the roadway to safely accomplish various driving maneuvers. Different maneuvers – emergency braking, passing, making a left turn at an intersection, etc. – each have their own sight distance design requirements. Later sections of this chapter address sight distance for different maneuvers, including stopping sight distance **[Section 5.2.1]**, intersection sight distance **[Section 5.2.2]**, decision sight distance **[Section 5.2.3],** and passing sight distance **[Section 5.2.4]**. Although these design requirements are expressed as a design <u>distance</u>, from the driver's perspective the critical aspect is <u>time</u>. It takes time to recognize a situation, understand its implications, decide on a reaction, and initiate the maneuver. While this process may seem almost instantaneous to us when driving, it can translate into hundreds of feet at highway speeds before a maneuver is even initiated. Speed is the factor that transforms road user time needs into distance requirements. Speed also can directly influence the requirements of the maneuver itself. This chapter addresses those human factors considerations that influence time and speed, and hence sight distance. Although the roadway designer and traffic engineer work with distances, sight distance requirements actually stem from driver time needs and speed choice. Therefore to understand, diagnose, and address sight distance concerns, one must address the human factors issues of time and speed.

Sight distance is an important concern for many specific roadway location elements (e.g., curves) and traffic engineering elements (e.g., signs) addressed in the subsequent chapters of this guide. Those chapters provide specific guidance dealing directly with those elements. This chapter addresses human factors issues at a general level that is relevant to many sight distance applications.

This chapter is intended to assist in situations where AASHTO sight distance standards **[AASHTO 2001 Chapter 3]** may be difficult to meet or may be less than optimal. Trade-offs among competing requirements sometimes require compromise decisions; in some cases, time requirements, based on measured driver behavior, may be less than those required by AASHTO. In other situations, conditions may make it desirable to meet or go beyond the standard requirement. The information and guidance provided in this chapter is intended to assist the engineer by recognizing the factors contributing to the behavioral components of the sight distance requirement.

5.1.2.2 Component Determinants of Sight Distance Requirements

There are several major components that together determine the sight distance that the driver requires to safely execute a maneuver.

Perception-reaction time (PRT). [Section 4.5] Before a driver can execute a maneuver, he or she must recognize there is a need for some action and decide what that action should be. Therefore this mental activity – detection, perception and cognition – precedes an overt vehicle control action and takes some amount of time. Perception-reaction time (sometimes also termed perception-response time) is typically defined as the period from the time the object or condition requiring a response becomes visible in the driver's field to view to the moment of initiation of the vehicle maneuver (e.g., first contact with the brake pedal). Although a particular PRT value (e.g., 2.5 s) is used in deriving sight distance requirements for a given design situation, this "reaction time" value should not be viewed as a fixed human attribute. PRT can take on a wide range of values depending upon many factors. Section 5.2 deals with these in more detail.

PRT is sometimes discussed as a sequence of stages. An example is the PIEV model (for Perception-Identification-Emotion-Volition), which is useful for illustration since it is cited in the MUTCD **[http://mutcd.fhwa.dot.gov/pdfs/2003r1/Ch2C.pdf]**. This model conceives of PRT as the sum of four stages: Perception (becoming aware of the presence of the object or event), Identification (understanding the object/event and its implications), Emotion (deciding what action to take), and Volition (translating the decision into overt action). Models of this sort are useful for pointing out the various perceptual and cognitive activities that must occur for a successful driver reaction. However, they over-simplify the process and the linear sequence of events is simply not a very complete or accurate description of driver cognitive activity. Section 5.1.2.3 provides further discussion of how the driver behavior assumptions of sight distance models differ from real-world driver behavior.

Maneuver time (MT) and maneuver distance. Maneuver time is the interval from the initiation of the vehicle control response (i.e., end of the PRT) to the completion of the driving maneuver. "Completion" is variously defined for different maneuvers, such as braking, turning, or passing. Section 5.2 considers these various maneuvers and what influences the time it takes to complete them.

The amount of distance needed for the safe and comfortable completion of the maneuver is dependent upon MT but also to other maneuver requirements. Maneuver distance (e.g., braking distance) is directly related to the physics of the situation (e.g., tire-pavement friction, grade), including vehicle performance capabilities. Maneuver time is also related to individual driver characteristics.

Speed selection. [Section 4.6; Chapter on Speed Control] Vehicle speed is what translates time requirements into distance needs. The operating speed determines the distance traversed while the PRT and MT are happening. Depending on the sight distance situation under consideration, the relevant speed may be that of the driver's own vehicle (as in stopping sight distance) or the speed of the approaching vehicle (as in stop-controlled intersection sight distance) or both (as in passing sight distance). In addition to providing the multiplier that converts PRT and MT to distances, speed can also affect distance requirements in several other ways. Maneuvers, such as braking, may require greater distances at higher speeds. Further, under some conditions speed can directly influence PRT, by altering how and where drivers allocate their attention. **[Section 4.2]** Finally, speed can influence the options the driver has and the difficulty and urgency of the decision. For sight distance considerations, then, an important question is, what factors influence a driver's choice of speed? In considering this, it is important to consider not only conscious driver decisions, but also perceptual factors that might influence a person's perception of speed **[Section 4.6]**. Section 5.3 deals with the influence of design factors on driver speed selection as related to sight distance.

In summary, sight distance requirements are jointly determined by PRT, MT, and speed selection. All of these are sensitive to a range of human factors considerations. Sight distance equations are based on simplified assumptions about road user abilities and behavior; if these assumptions are inappropriate for a given application, the actual driver behavior may not match the predicted behavior and road design may not be adequate.

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Figure 5.1 Animation showing the influence of human factors variables on stopping distance

Animation: show two parallel animations, from driver's eye view and diagram view.
In both cases, child pedestrian enters road 300 feet ahead of vehicle on a 40 mph road. Run the animations in slow-motion, indicating point of detection, recognition, brake initiation, stopping.

Left side:	Expected	Right side:	Unexpected
	High contrast		Low contrast
	Simple background		Complex background
	Simple Tangent		Geometric feature
	Alert driver		Distracted
	No other traffic		Vehicle in next lane
	Traveling at speed limit		10 mph over limit

Driver's-eye view of road	**Driver's-eye view of road**
Bird's-eye view of road, including vehicle, child	**Bird's-eye view of road, including vehicle, child**

****

5.1.2.3 REAL-WORLD DRIVER BEHAVIOR VERSUS DESIGN MODELS

This section discusses how driver behavior, as represented in sight distance models, may differ from actual driver behavior. Design models use simplified concepts of how the driver thinks and acts. This simplification should not be viewed as a flaw or error in the sight distance equations. These models are a very effective way of bringing human factors data into design equations in a manner that makes them accessible and usable. After all, the intent of a sight distance equation is not to reflect the complexities of human behavior but to bring what we know about it into highway design in a practical way. However, like any behavioral model, models for deriving sight distance requirements are not precise predictors of every case and there may be some limitations to their generality. Therefore it is useful to understand certain basic principles of human behavior in driving situations to better interpret these models and how they may differ from the range of real-world driving situations.

Sight distance formulas for various maneuvers (presented in Section 5.2) differ from one another, but they share a common simple behavioral model as part of the process. The model assumes that there is some time required for perception and reaction (PRT), followed by some time (MT) and/or distance required for executing the maneuver, and some vehicle speed in effect during these times. Sight distance equations for some maneuvers may contain additional elements or assumptions, however, all have this basic two-stage model somewhere at their core.

The two equations below show two versions of the general two-stage model. In both cases, the first term shows the distance traveled during the PRT phase and the second term shows distance traveled while executing the maneuver. The difference is that the first equation shows a case where the distance traveled while executing the maneuver is based on the time it takes to make that maneuver (for example, the time to cross an intersection from a Stop). The second equation shows a case where the distance traveled while executing the maneuver is based directly on the distance required to complete the maneuver (for example, braking distance for a emergency stop). For both forms of this general equation, vehicle speed (v) influences the second (maneuver) component. The general form of the sight distance equation is:

$d = kVt_{prt} + kVt_{man}$, where maneuver *time* is input

or

$d = kVt_{prt} + d_{manV}$, where maneuver *distance* is input

where:
d = required sight distance
V = velocity of the vehicle(s)
t_{prt} = PRT
t_{man} = MT
d_{manV} = distance required to execute a maneuver at velocity V
k = a constant to convert the solution to the desired units (feet, meters)

This model shows that the sight distance requirement is composed of (at least) two distances: there is a distance traveled while the driver perceives and evaluates a situation (determined by PRT and vehicle speed) and a distance traveled while executing the maneuver (determined by maneuver time/distance and vehicle speed). Figure 5.2 shows this simple model diagrammatically. As the figure shows, the PRT component is itself viewed as a series of steps. These individual steps are not explicit in the design equation but are included in the assumptions that underlie the PRT value. **[Section 4.5]** Design equations and their assumptions for specific maneuvers are dealt with in subsequent sections of this chapter. The sequential model of driver behavior shown in Figure 5.2 is a shared common conceptual underpinning of various sight distance equations.

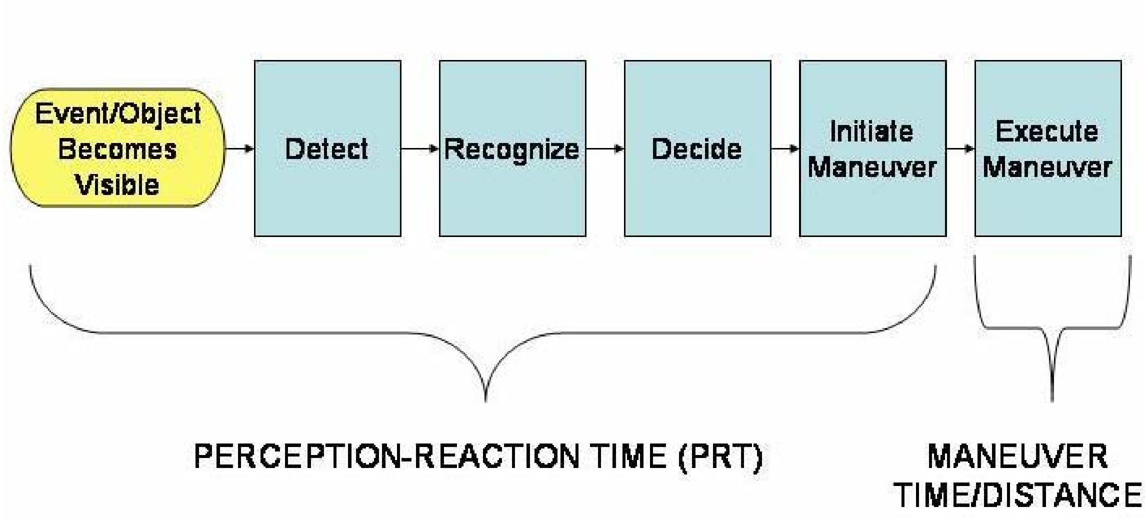

Figure 5.2. Diagrammatic version of the basic sight distance model

The figure shows the linear chain of steps that comprise the PRT, and after the PRT is complete, the execution of the selected driving maneuver. As a description of what actually happens during driving, we can treat this model as a "convenient fiction." It is a simple, fixed, linear, mechanistic process. As such, it provides a useful basis for deriving approximate quantitative values for design requirements that work for many situations. Real human behavior is far more complex than this. However, the highway designer or traffic engineer needs to work with less complex models of human visual perception, attention, information processing, and motivation. What is important, however, is to appreciate those factors that may affect application of design sight distance models for particular situations. This will help to prevent, recognize, or deal with sight distance issues. For a particular situation, the standard sight distance design equation might either underestimate or overestimate the actual needs of a driver. Subsequent sections of this chapter deal with specific factors that affect the human factors of the driver response and provide guidance for working with them. Before looking at these specific applications, it is useful to have an appreciation of how the simple driver models that underlie sight distance requirements contrast with the real complexities of driver behavior.

Some places where actual driver behavior contrasts with the underlying basic sight distance model include the following:

- What happens prior to encountering the object/event? The model shown in Figure 5.2 is not sensitive to things that happen prior to the moment that the potentially hazardous object or event becomes visible to the driver. In reality, the readiness with which drivers react may be strongly influenced by what happens leading up to the event. For example, drivers traveling on a roadway with few access points and little traffic may be unprepared to stop for a slow moving vehicle ahead. In contrast, if drivers had been encountering numerous commercial driveways and intersections, with entering truck traffic, they might more readily react to the vehicle. Roadway design and operational features in advance of the situation therefore are important influences that are not explicit in the basic model. Figure 5.3 shows an expansion of the basic model to include as a stage what happens prior to the object/event.

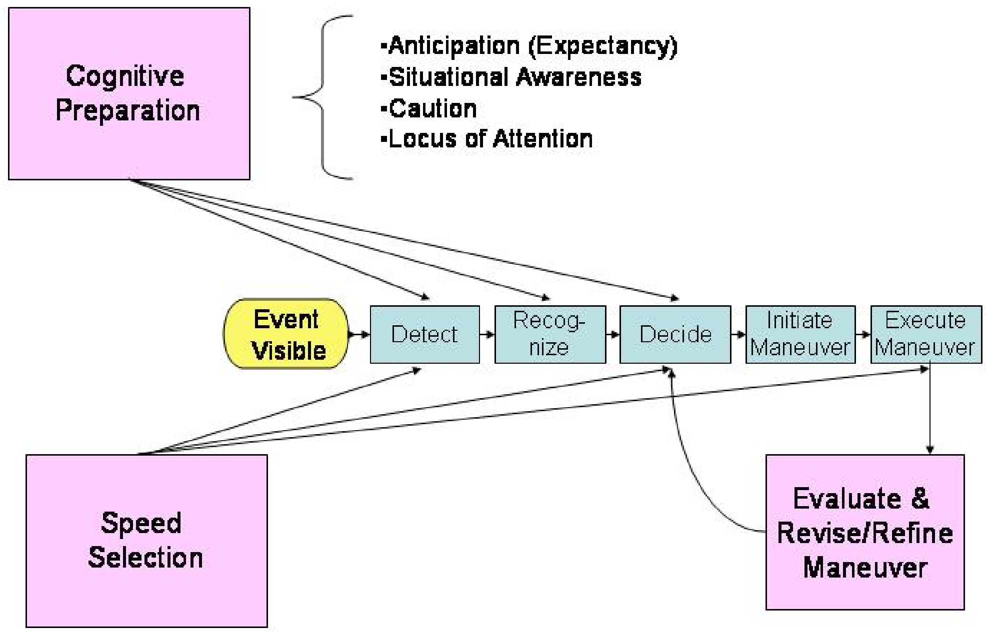

Figure 5.3 Added components to basic sight distance behavioral model

In the figure, two additional components to the model are shown prior to the event becoming visible. One component is labeled “cognitive preparation.” This is a general term to encompass various active mental activities that can influence response times and decisions. These include such things as driver expectancies **[Section 4.4]**, situational awareness **[Section 4.2]**, a general sense of caution **[Section 4.7]**, and where attention is being directed **[Section 4.2]**. Part II (“Bringing Road User Capabilities into Highway Design and Traffic Engineering Practice”) of this manual **[Section 2.0]** provides some further explanation of these factors. As the arrows in the figure show, the driver’s cognitive preparation as he or she encounters the object/event can influence the speed of detection, the speed and accuracy of recognizing the situation, and the speed and type of decision made about how to respond. The critical point is that PRT at some point on the road is influenced by what drivers encounter as they approach the site.

The other component in Figure 5.3 that occurs prior to the visible hazardous object or event is speed selection **[Section 4.6, Chapter X on Speed Control]**. As discussed earlier, speed can have perceptual effects, influencing how easily a target object is detected or how accurately gaps are judged. Speed may affect the driver’s sense of urgency, which can influence what maneuver options are considered and their relative appeal. Speed also may directly effect the difficulty, as well as the required time or distance, of the maneuver. Therefore whatever influences speed choice prior to the event may influence the driver decision process, as well as impacting the time available for the driver response.

The basic sight distance behavioral model (Figure 5.2) makes assumptions about driver cognitive state and speed choice as the hazardous event is encountered. In reality, the driver does not arrive at the situation as a “blank slate.” The locus of a sight distance problem, or its solution, therefore may turn out to be in advance of the problem site itself.

- Information processing **[Section 4.3]**. The behavioral model shows a chain of mental and physical events occurring in a sequential fashion. A key bit of information becomes visible; the presence of this event is detected; once detected, it eventually becomes recognized and understood; then a decision is made about what maneuver is needed; then that action gets initiated; and once initiated, the maneuver runs off. Each step takes some amount of time, and one step does not begin until the previous step is complete. This assumed "serial processing" model is one way a driver *could* respond, but it is not typical. For example, if drivers see some vague object ahead that might or might not be in the roadway, they may begin to brake even before the object is recognized. Once the object is recognized, the maneuver may be reconsidered. The mental processes shown by the various boxes in Figure 5.2 may actually occur in parallel, in a different sequence, and with modifications (feedback loops) as the process continues. The assumed linear response sequence is therefore really a special case used for design purposes. It should not be viewed as a necessarily realistic representation of the more complex perceptual and cognitive activity in complex driving situations.

- Smooth driving versus a series of episodes. Related to the point above, the model underlying driver sight distance requirements could be described as "episodic." Some object or event occurs, then some driver reaction to it takes place. Then another object or event occurs, and another reaction takes place. Real driving is normally smooth and continuous; it is not a jerky sequence of little episodes. Yet for ease of analysis, we often break driver behavior into little stimulus/response events, or treat the roadway as a succession of discrete segments or zones. To the driver, the roadway and the driving task are generally smooth and continuous. Real drivers do not just react; they plan and predict and manage and adapt to events as they go along. This view of driver performance is much more difficult to model and quantify, especially in a manner that easily will generate a simple design parameter. From a human factors perspective, sight distance models are based on a little bit of behavior that describes how a driver *might* react, and not on how drivers typically behave. However, this is generally reasonable from a design perspective, because it is somewhat conservative: those drivers who encounter a situation without planning or anticipation are those likely to be most in need of the full sight distance requirement.

- The hazard. For each sight distance design application, the analysis is based around some object, event, or roadway feature that must be responded to with a driving maneuver. That cue might be debris in the roadway, braking by a vehicle ahead, an approaching vehicle on a conflicting path, a freeway lane drop, a change in signal phase, a pedestrian entering the road, a railroad gate, an animal, a vehicle entering from a driveway, or many other things. The PRT process begins with the potentially hazardous object or event (the "visual target") becoming visible to the driver **[Section 4.1]**, followed by some time to visually detect and recognize that target. Design equations have to include some estimate of when something becomes visible and how long driver reaction will take. The examples of various hazards suggest just how different these may be as visual targets, so making a single assumption is an obvious simplification. A target object may be large or small, bright or dull, familiar or unfamiliar, moving or stationary, or have other attributes that affect the speed of detection and recognition. Explicitly or implicitly, design equations have to make some assumption about the characteristics of the visual target. Furthermore, visibility conditions may vary with weather, glare, light condition, roadway lighting, and intervening traffic (especially truck traffic). Again, design equations must be based on some assumption about visibility conditions.

  A PRT model requires the user to be able to specify the point in time or space that the hazard becomes visible to the driver. This, too, is sometimes an over-simplification. For example, there is no sharp threshold where an object in the road suddenly goes from being invisible to visible. Some hazards do not occur all at once, but evolve over some time, such as a vehicle moving into a lane in front of a driver. Some events might have a preview, such as a vehicle positioned in a driveway prior to its pulling out, or children playing near the road prior to entering the road. Some events might have multiple cues. For example, a freeway lane drop has signing, an initial taper, lane markings, and the point where the lane finally disappears. Sometimes the important visual target is not the hazard object or event itself but a cue about the hazard. For example, brake lights on a vehicle ahead may be a warning about a sudden severe deceleration, but they may also reflect a minor tap on the brake. Drivers cannot respond to the brake light in the same way they respond to recognition of the actual deceleration.

- The response. The behavioral components of sight distance models are based around some very specific maneuver in response to the object/event, with fixed assumptions about response parameters. For example, for responding to an unexpected need to stop, AASHTO (2001) **[AASHTO chapter 3]** assumes a braking maneuver with a deceleration of 3.4 m/s^2 (11.2 ft/s^2). Braking may be *a* reasonable response to assume, and 3.4 m/s^2 may be *a* reasonable deceleration to assume, but this certainly does not mean that braking at this rate is *the* driver response to an unexpected hazard. The maneuver time and maneuver distance components of sight distance models are in many cases based on good empirical research and human factors considerations and work well for most applications. Still, the use of a single standard value is a convenient simplification. Actual maneuvers can be influenced by various factors. The perceived urgency of the situation (based on available time/distance, driver/vehicle capabilities) determines options and shapes the way drivers' respond, and often there are multiple options. For example, for an unanticipated stop, a driver may brake severely, or brake gradually and steer around, or swerve sharply. The surrounding physical, traffic, and social environment will affect these options: is there a lane or shoulder to steer around, are there adjacent or following vehicles, is the obstacle a piece of debris or a child, is there a passenger in the vehicle? Drivers also make a trade-off of speed versus control when executing maneuvers. The AASHTO deceleration value of 3.4 m/s^2 represents an estimate of a "comfortable deceleration" with which almost all drivers can maintain good vehicle control. In this sense it is appropriate for general design, but does not necessarily describe what drivers can do or actually do. Furthermore, once a driver initially selects and begins to execute a particular maneuver, that action does not simply reel off in a fixed manner. As Figure 5.3 illustrates, the situation is monitored and the maneuver is re-evaluated as it is being executed. The response may be refined or modified as it progresses. Drivers may not respond to a situation with a maximum response, but rather may initiate a more controlled action and monitor the situation before committing to a more extreme action. For instance, they may begin gradual braking and check their mirrors for following traffic before decelerating more sharply or swerving.

- The driver. The diverse driving population ranges widely in capabilities and behaviors **[Section 4.0]**. Drivers vary in visual acuity, useful field of view, eye height, information processing rate, tolerance for deceleration, and other factors related to PRT and MT. A design equation is based around a design driver with some assumed set of attributes. For conservatism, the assumptions usually do not represent a typical driver, but rather poorer performing individuals (e.g., 15th percentile in terms of some attribute). Assumptions are made about the state of the driver as well. For example, data are generally based on drivers who are sober and alert. Yet impaired or fatigued drivers **[Section 4.9]** may represent a large part of the crash risk. Alcohol, drugs, medication, and fatigue can have dramatic effects on the psychological processes that underlie PRT and maneuver execution. Driver distraction by activity within the vehicle is also a common occurrence that is not reflected in the design model. In-vehicle technologies, such as cell phones, navigation systems, and infotainment systems are increasingly common. The "multitasking" driver **[Section 4.2]** is an increasing concern, but PRT models do not reflect this possibility.

- Empirical findings. The values used in design equations may or may not derive from good empirical sources. In some cases (e.g., brake reaction time) there are numerous empirical studies and reasonably good agreement among them. In other cases, empirical data are very limited. The numbers that come from empirical studies are sometimes questionable on a number of grounds: the sample of drivers is small or unrepresentative; the situations evaluated are limited and may not generalize well; the research may be out of date (given changes in roadways, traffic, vehicles, traffic control devices, driver norms); the research setting (test track, simulator, laboratory) may lack validity; and there may be conflicting results with other studies. It would be wrong to assume that sight distance design equations are necessarily based on a strong empirical foundation that readily generalizes to all cases.

  General design equations based on simple behavioral models cannot incorporate site-specific considerations. Empirical observations made at the site may be at variance with the predicted behaviors. Even when design equations are based on "good" data, the generality of the models suggest that credence be given to any empirical data that can be collected at the site itself.

In summary, sight distance requirements are based on a highly simplified and mechanistic model of driver behavior and capabilities. This is a reasonable and generally successful approach. The general assumptions often work well enough to approximate the needs of most drivers. But it is important to recognize that this simple model has a number of limitations as a description of actual driver performance. When diagnosing or addressing difficult sight distance problems, it may be useful to recognize how design models simplify driver actions and to acknowledge realities of more complex driver perception and behavior.

5.1.3 The Relationship of This Chapter to Other Key Reference Documents

This sight distance chapter is related to the following key references:

AASHTO *Policy on Geometric Design of Highways and Streets* (2001)
- Chapter 2, Design Controls and Criteria: discusses driver reaction time and related issues in Driver Performance subhead
- Chapter 3, Elements of Design: section on sight distance, with subsections on stopping sight distance, decision sight distance, passing sight distance, sight distance for multilane highways
- Chapters 5 (Local Roads and Streets), 6 (Collector Roads and Streets), 7 (Rural and Urban Arterials), and 9 (Intersections) all have specific subsections on sight distance

Manual on Uniform Traffic Control Devices (2003)
- The MUTCD has several tables relating minimum sight distance to speed. These include Table 3B-1 (for passing sight distance), Table 4D-1 (for traffic control signal sight distance), Table 6C-2 (for work zone tapers), and Table 6E-1 (for work zone flagger stations)
- Section 2C.05, Placement of Warning Signs, describes a PRT model known as the PIEV (Perception-Identification-Emotion-Volition) model. Tables 2C-4 (metric units) and 2C-5 (English units) show advance warning sign placement as a function of speed based on PIEV time requirements.

ITE *Traffic Engineering Handbook* (1999)
- Chapter 2, Road Users, has sections on perception-reaction time and sight distance
- Chapter 11, Geometric Design of Highways, has a section on sight distance, with subsections on stopping sight distance, passing sight distance, decision sight distance, and intersection sight distance

ITE *Traffic Control Devices Handbook* (2001)

- Chapter 2, Human Factors, has sections on driver perception reaction time, maneuver time
- Chapter 11, Highway-Rail Grade Crossings, contains discussion of sight distance requirements for at-grade crossings

Highway Safety Manual (under development)

- Planned section 2.4, Fundamentals: Human Factors in Road Safety will include perception-reaction time and related human factors issues
- Sight distance may be expected to included in various places in Part II – Knowledge, but these chapters have not yet been developed

Highway Design Handbook for Older Drivers and Pedestrians (2001)

- Rationale and Supporting Evidence section contains evaluation of perception-reaction time and sight distance requirements for older drivers
- Various design recommendations to support older drivers include consideration of older driver perception-reaction time and sight distance needs

5.2 Design Sight Distances

Design sight distances that depend on driver PRT and MT are as follows:

- Stopping sight distance
- Intersection sight distance
- Decision sight distance
- Passing sight distance
- Railroad-highway grade crossing sight distance

In this general chapter, only two of the eleven cases of intersection sight distance defined in AASHTO (2001, Chapter 9) are considered. The remainder are considered in the chapters on intersections. **[Chapter 10, 11]** Similarly, railroad-highway grade crossing sight distance is not considered here, but dealt with in the railroad-crossing chapter. **[Chapter 14]**

The appropriate values for PRT and MT depend on the specific driving task underlying the sight distance requirement. They also depend on the degree of urgency. Drivers responding to a child running into the road are likely to have much shorter PRT and MT than might be the case for debris on the road. Drivers who see cues to an upcoming lane drop well back from the gore will have longer PRTs and MTs than drivers who are near the gore when they suddenly realize they must change lanes. Ideally the highway should be designed to allow for comfortable, less stressful responses. Although there are many studies of PRT and MT, very few determine how comfortable the driver found the driving task for a given PRT and MT.

The following sections provide, for each type of sight distance:

- Definition
- High Priority Considerations
- Guideline for PRT
    - Under baseline conditions

    - Under unfavorable conditions
- Guideline for MT
    - Under baseline conditions
    - Under unfavorable conditions
- Rationale for Guideline
- Summary Table

Definition: Each sight distance definition is taken from the AASHTO Policy on Geometric Design of Highways and Streets (2001).

High Priority Considerations: AASHTO sight distances should always be provided. However, if a given sight distance is below standard at a number of locations, or if design tradeoffs must be made at a given location, then priorities must be set. High priority considerations give guidance in making design tradeoffs and setting priorities with respect to driver needs.

Baseline Conditions: PRT and MT values given are generally 85th percentile or more values, since these include the majority of the driving population. Not all studies provide such values and in some cases, 85th percentile values are calculated from means and standard deviations. Older, novice, and unfamiliar drivers in passenger vehicles are the assumed baseline in addition to any other factors specifically noted.

Unfavorable Conditions: Design (e.g. unusual geometric layout), environmental (e.g. nighttime) and operational conditions can increase driver requirements in some circumstances. Guidance is provided for those conditions for which data are available or for which the direction of effect on PRT or MT for a given variable (e.g. nighttime, unusual geometric layout, higher workload driving task) can be predicted. Driver characteristics including age, impairment (fatigue, alcohol, medical conditions), and familiarity affect PRT and MT, and where appropriate these will be discussed (see Chapter 2 **[Chapter 2]** for an extensive discussion of driver characteristics).

Rationale: The rationale section provides a short summary of the studies used to develop the PRT and MT guidelines.

Summary Table: This table provides a summary of the driver, operational and geometric factors that affect PRT and MT, guideline PRT and MT values, guideline SD values and AASHTO values for comparison.

5.2.1 Stopping Sight Distance

5.2.1.1 DEFINITION: SSD **[AASHTO 2001 Ch 3]**

Stopping sight distance, as referred to by AASHTO (2001) "should be sufficiently long to enable a vehicle traveling at or near design speed to stop before reaching a stationary object in its path."

SSD is defined as follows:

Metric	US Customary
$SSD = 0.278\, Vt_{PRT} + 0.039 \dfrac{V^2}{A}$	$SSD = 1.47\, Vt_{PRT} + 1.075 \dfrac{V^2}{A}$
where: t_{PRT} = brake reaction time, 2.5 s V = design speed km/h A = deceleration rate, m/s^2	where: t_{PRT} = brake reaction time, 2.5 s V = design speed, mph A = deceleration rate, ft/s^2

The current AASHTO value for PRT is 2.5 seconds. MT assumes that drivers are 100% efficient in braking, i.e., locked wheel braking, and that pavement friction is very poor.

5.2.1.2 High Priority Considerations: SSD

Stopping sight distance should always be provided because any road location can become a hazard. A study (Fambro et al., 1996) found that the most common objects hit on sight-restricted curves were large animals and parked cars, the presence of which can create a hazard on any road section. If stopping sight distance is below standard at a number of locations then priorities must be set. Examples of hazards and conditions which are high priority with respect to the need for stopping sight distance are:

- Change in lane width
- Reduction in lateral clearance
- Beginning of hazardous fill slope
- Crest vertical curve
- Horizontal curve
- Driveway
- Narrow Bridge
- Roadside hazards – e.g., boulder markers at driveways
- Unmarked crossovers on high-speed rural arterials
- Unlit pedestrian crosswalks
- High volume pedestrian crosswalks
- Frequent presence of parked vehicles very near or intruding into the through lane
- Slow moving vehicle
- Frequent pedestrian or bicycle presence

5.2.1.3 Guideline for SSD

Guidelines for SSD PRT and MT are shown on the next two pages.

STOPPING SIGHT DISTANCE: PERCEPTION-REACTION TIME GUIDELINE

Under baseline conditions: Most reasonably alert drivers (95%) will be able to initiate braking within PRT of 1.6 s.

- Daytime
    - Hazard clearly visible and directly in driver's line of sight
- Nighttime
    - Self-illuminated or retro-reflectorized hazard, with a lighting configuration that is immediately recognizable, near driver's line of sight

Under unfavorable conditions: Once the object is detectable, PRTs in unfavorable conditions can be 5 s or more.

- Daytime
    - Hazard camouflaged by background and initially off line of sight
- Nighttime
    - Hazard unreflectorized and not self-illuminated
    - Hazard self-illuminated or retro-reflectorized but lighting configuration is unfamiliar to the driver
    - Low beam headlights with or without streetlighting
    - Hazard off line of sight
    - Glare from oncoming vehicles or commercial lighting

PRT does not start until drivers can see and, to some degree, recognize the hazard. The distance at which drivers can see an unilluminated, unreflectorized hazard depends on their headlights, their sensitivity to contrast and on their expectation of seeing the hazard. When drivers are not expecting a particular low contrast hazard (e.g. unreflectorized jersey barrier), their seeing distance is one half that that would pertain if the object were expected. At speeds of 60 km/h and greater, using low beam headlights, most drivers will be too close to an unexpected, unreflectorized hazard at the point they can detect it in time to stop. A very low contrast hazard may not even be detected in time to start braking. Therefore objects blocking the road path, such as traffic islands or jersey barriers in a construction zone must be reflectorized.

Drivers confronted with an unusual lighting configuration (e.g. a white worklight on the rear of a tractor, or a flat bed trailer's single amber light in the middle of a lane) may not begin the PRT until they can determine what the light is attached to.

PRT can be increased by the following driver factors:

- High workload (e.g. traffic merging, several signs to be read)
- Fatigue and impairment

STOPPING SIGHT DISTANCE: MANEUVER TIME GUIDELINE

Under baseline conditions: Based on Fambro et al. (1997), a study conducted on flat road sections, and dry pavements, the mean constant deceleration is about 0.55 g (69% of the pavement's coefficient of friction), and the 85th percentile is 0.38g (60%). On dry pavements no difference between ABS and standard brakes is expected.

- Tangent
- Dry or wet pavement
- No grade
- Passenger vehicles
- Unexpected object
- Tires in good condition

Under wet conditions, with standard brakes, the mean constant deceleration is about .43g (54% of the pavement's coefficient of friction), and the 85th percentile is .38g (47%). On wet pavements with ABS, the mean constant deceleration is about 0.53g (66% of the pavement's coefficient of friction), and the 85th percentile is about 0.45g (56%).

Under unfavorable conditions: Slightly lower braking efficiencies (by 2 – 8%) are obtained on curves. Based on physics, downgrades increase MT. No human factors studies are available. The assumed decrease in MT is V*f*grade%.

- Curve versus tangent
- Downgrade

MT can be increased by the following driver factors:

- Age
- Gender

Older drivers and women will not apply as much braking force as younger drivers and males.

5.2.1.4 BASIS/RATIONALE FOR SSD GUIDELINE

SSD PRT

Stopping sight distance PRT has been addressed in a variety of experimental studies. The principal studies include the following:

- Daytime PRT for clearly visible hazard placed on the road (Olson, Cleveland, Fancher, & Schneider, 1984)
- Daytime PRT for clearly visible hazard emerging from the side of the road (Lerner, Huey, McGee, & Sullivan, 1995)
- Nighttime studies for unilluminated, unreflectorized hazards placed on the road (Olson & Sivak, 1983; Fambro, Fitzpatrick, & Koppa, 1997)
- Simulator studies of PRT for low contrast targets on the side of the road (Ranney, Masalonis, & Simmons, 1996)

- Nighttime on-road study comparing detection distance for alerted and unalerted drivers (Roper & Howard, 1938)

In a daytime study conducted for the purposes of assessing the established AASHTO value for PRT in a stopping sight distance situation, Olson et al. (1984) measured PRT for a group of drivers who suddenly encountered objects of various sizes in the middle of their lane as they crested a hill in the daytime. PRT was defined as the time elapsed between when the object first became visible until the point at which it was detected by the driver. The 85th percentile PRT for 49 young subjects was 1.3 seconds, and for older drivers, very similar at 1.4 seconds.

In a study conducted by Lerner et al., subjects encountered a yellow barrel released at a predetermined point (on average 3.4 sec away) which rolled to the edge of the lane, restrained by chains (Lerner et al. 1995). Data were collected from 30 subjects aged 20 – 40 years, 43 subjects aged 65 – 69 years and 43 subjects aged 70+. The 85th percentile PRT was 1.9 seconds, and this value was the same for the older and younger age groups. The longest observed PRT was 2.5 seconds.

Fambro et al. (1997) conducted two studies involving unexpected hazards, the first being a barricade that popped up suddenly in front of the driver and the second, a barrel which rolled off a truck parked by the side of the road. In both cases the hazards would have sufficiently contrasted with the background against which they were seen to have been immediately detectable. Based on 22 younger (age 24 years or less), and 24 (age 55 years or more) older subjects, the 95th percentile PRT was 2.0 seconds. There was no difference between younger and older subjects in response to unexpected hazards.

As the object to be detected becomes more difficult to see, because of low contrast and/or low light levels or glare, PRT lengthens. In a study conducted in a driving simulator with 8 middle-aged subjects (aged 38 to 62 years) Ranney et al. 1996 examined PRT in response to a low contrast pedestrian target at the side of the road. Once the target was detectable, the mean PRT was 2.8 seconds and, assuming a normal distribution, based on the reported standard deviation, the 85th percentile PRT was 3.9 seconds, when no glare was present. This increased to a mean PRT of 3.5 seconds and an 85th percentile PRT of 4.9 seconds when glare equivalent to that of an oncoming vehicle was present.

In a study of nighttime detection of various hazards that might be encountered on a road (e.g. animal, tire, tree limb, etc.) Fambro et al. (1997) found that drivers do not have the visual capabilities to recognize objects that are less than 30 cm (11 inches) in height at or beyond the AASHTO minimum stopping sight distance of 128 m. (420 ft) at 90 km/h (56 mph). PRT cannot start until drivers detect and partially, at least, recognize the detected object.

Two studies have shown that when drivers are not expecting to see an object, the distance at which they see it is considerably less when they know they are about to encounter it (Roper and Howard,1938; Shinar, 1985). Based on the Roper and Howard (1938) study, in which subjects were as unalert as it is probably possible to be in an experimental study, Olson (2002) estimated that at 35 km/h (22 mph) fewer than 10% of unalerted drivers would be able to see an unreflectorized target (a pedestrian in a dark coat) on the left hand side of the road, and less than half would be able to see the same target on the right hand side of the road, in time to stop (Olson, 2002).

SSD MT

Stopping sight distance MT from 88 km/h (55 mph) for typical drivers, as opposed to test drivers, was recorded by Fambro et al. (1997) in the studies involving unexpected hazards described above, on pavement with a coefficient of friction of 0.8 g in dry conditions on a flat surface. When research participants used their own vehicles and responded to an unexpected object, on dry pavements, the mean constant deceleration was 0.55 g, and the 85^{th} percentile, 0.48 g. When research participants used test vehicles, they decelerated more rapidly than they did in their own vehicles, with an equivalent constant deceleration that was about 14% higher. In this study no differences were found in braking efficiency between ABS and standard brakes on dry pavements.

Under wet conditions, with standard brakes, the mean constant deceleration was about 0.43 g, and the 85^{th} percentile, 0.38 g. On wet pavements with ABS, the mean constant deceleration was about 0.53 g, and the 85^{th} percentile was about 0.45 g.

In the study in which drivers used test cars, slightly higher g values (by 2 - 9%) were obtained on tangents as compared to curves.

In a study similar to the Fambro et al. (1997) study, in virtually every braking situation tested, drivers stopped rapidly, but not to the point of locked wheel braking (Lerner et al., 1995). In locked wheel braking drivers are 100% efficient in making use of the available pavement friction. Locked wheel braking is typical in accidents.

Clearly urgency plays a major role in determining braking MT's. At intersections, when time gaps are 10 seconds or less, Harwood et al. (1996) found that major road vehicles slow by an average rate of 0.68 m/sec^2 (2.2 ft/sec^2), to accommodate entering minor road vehicles. For traffic decelerating at traffic lights, Wortman and Matthais found an average rate of 3 m/sec^2 (10 ft/sec^2). Given the coefficient of friction for the pavement used in the Fambro et al. study, the average rate of braking was 4.7 m/sec^2 (15.4 ft/sec^2) on dry pavement (Wortman & Matthais, 1983).

For design purposes, neither rapid nor locked wheel braking is a desirable driver response, given the risk of a rear-end crash when there is a following vehicle. Although the AASHTO model assumes locked wheel braking, it also assumes poor pavement and tire conditions, neither of which may be present, making the assumption of locked wheel braking less problematic.

The AASHTO model also assumes constant deceleration throughout the braking maneuver, and Fambro et al. found that deceleration profiles are not linear. Maximum deceleration was generally not exhibited until the last part of the braking when the vehicle had slowed and come closer to the unexpected object. The mean maximum deceleration was about 75% of the pavement's coefficient of friction. Under wet conditions, the 95^{th} percentile value for equivalent constant deceleration without ABS was 0.29 g (equivalent to 2.8 m/sec^2 (9.3 ft/sec^2), and with ABS, 0.41 g (equivalent to 4 m/sec^2 (13.2 ft/sec^2).

SUMMARY: SSD

PRT Factors	PRT	MT Factors	Mean Deceleration (g)	AASHTO
Driver workload Poor visibility Low contrast hazard Hazard off line of sight Unfamiliar object	1.6 to 5+ sec	Driver age Urgency	60% f dry 56% f wet 47% f wet ABS	2.5 sec + 100%f

f = pavement coefficient of friction

5.2.2 Intersection Sight Distance

5.2.2.1 DEFINITION: ISD

Intersection sight distances (ISD) are the minimum sight distances required for drivers to safely negotiate intersections, including those with no control, stop control and signals, and including those for drivers turning left, right and going straight through. Until the 2001 version of the AASHTO Policy, ISD values have been calculated using models that assume a serial process whereby PRT is completed while the driver is stopped at the stop bar, followed by an acceleration time. For the simplest form of ISD, involving crossing or turning from a stop control on a minor road, the equation form used was:

Metric	US Customary
$ISD = 0.278\ V_{major}(J + t_a)$	$ISD = 1.47\ V_{major}(J + t_a)$
where: ISD = intersection sight distance (length of the leg of sight triangle along the major road (m) V_{major} = design speed of major road (km/h) J = PRT required to determine if an available gap or lag is acceptable (s) t_a = MT to accelerate and traverse the major highway pavement (for a crossing maneuver) or to accelerate and reach 85% of the major highway design speed (for a turning maneuver (s))	where: ISD = intersection sight distance (length of the leg of sight triangle along the major road (ft) V_{major} = design speed of major road (mph) J = PRT required to determine if an available gap or lag is acceptable (s) t_a = MT to accelerate and traverse the major highway pavement (for a crossing maneuver) or to accelerate and reach 85% of the major highway design speed (for a turning maneuver (s))

There were seven AASHTO model situations (Case 1-V with 3 variations for III) which dealt with through, left and right turning maneuvers at intersections with no control, stop control, yield control and signal control. The values used in the AASHTO equations were based on limited empirical data.

In the 2001 AASHTO Policy, ISD is no longer based on the serial model assuming that PRT starts when the driver is stopped at the stop bar, is completed before leaving the stop bar, followed by an acceleration time. Instead ISD is based on a gap acceptance model, in which the time gaps accepted by drivers for the various maneuvers made at intersections are the basis. Although gap acceptance is an alternative means of conceptualizing driver requirements for ISD, this does not imply that the various elements of the traditional sight distance model (Figures 5.2 and 5.3) are not important at intersections. PRT is completed once drivers have decided to accept the gap, but before they move forward. The time gap accepted must be of sufficient length to accommodate their estimated MT, without requiring substantial braking from the oncoming driver. The new model uses an equation form as follows:

Metric	US Customary
$ISD = 0.278\ V_{major} t_g$	$ISD = 1.47\ V_{major} t_g$
where: ISD = intersection sight distance (length of the leg of sight triangle along the major road (m) V_{major} = design speed of major road (km/h) t_g = time gap for minor road vehicle to enter the major road(s)	where: ISD = intersection sight distance (length of the leg of sight triangle along the major road (ft) V_{major} = design speed of major road (mph) t_g = time gap for minor road vehicle to enter the major road(s)

In these equations, t_g is the gap in seconds accepted by drivers 50% of the time it is presented for crossing or turning maneuvers. In the 2001 AASHTO Policy, there are a total of 11 AASHTO model situations which deal with: through, left and right turning maneuvers at intersections with no control, 4 way stop control, 2 way stop control, yield control and signal control from the minor road. In addition ISD for a left turning maneuver from the major road is considered. The object height is considered to be equivalent to the driver's eye height of 1.08 m (3.5 ft) above the surface of the intersecting road.

From a driver behavior perspective, it should be noted that both the PRT-based ISD equations and the gap acceptance ISD equations contain an assumption of some cooperative behavior from the conflicting (major road) traffic. If approaching traffic does not slow to some degree, the equations may not work. AASHTO (2001) notes that the values given for sight distance (e.g., Exhibit 9-54) "provide sufficient time for the minor road vehicle to accelerate from a stop and complete a left turn *without unduly interfering with* major-road traffic operations." [*emphasis added*] Further considering the values for the gap acceptance model, AASHTO states: "Observations have also shown that major-road drivers will reduce their speeds to some extent when minor-road vehicles turn onto the major road. Where the time gap acceptance values in Exhibit 9-54 are used to determine the length of the leg of the departure sight triangle, most major road drivers should not need to reduce speed to less than 70 percent of their initial speed." The previous PRT-based models also contained assumptions that major-road traffic may have to slow from design speed (AASHTO, 1990). For example, left and right turning maneuvers from a stop are based on the time it takes for the turning vehicle to achieve 85% of design speed before being overtaken by vehicles on the major road "that are approaching the intersection from the (left or right) and are reducing their speed from the design speed to 85 percent of the design speed."

In the guideline below ISD is considered for turning and crossing maneuvers from a minor road with a stop control. Guidance for other ISD situations is considered in more detail in a later chapter on intersections.

5.2.2.2 High Priority Considerations: ISD PRT

It is particularly important to provide adequate intersection sight distance wherever a significant level of visual clutter or overload exists, for example where there are:

- High major road volumes
- Complex signs (multiple destinations, route shield assemblies)

- Complex pavement markings (multiple turn lanes)
- Complex or atypical intersection geometry
- Visual clutter in urban areas due to commercial lighting
- A high percentage of older drivers.

It is also important to provide adequate intersection sight distance wherever drivers are less likely to be expecting to respond to an intersection, for example:

- Requirement to stop is unexpected due to right of way on previous road section
- Stop or signal controlled isolated intersection
- Intersections with high volume but signals not yet warranted

In these situations, ISD is a minimum – it is preferable to provide DSD **[Section 5.2.3]**.

5.2.2.3 GUIDELINE FOR ISD

Because of the recent change in AASHTO Policy ISD has been considered both from the perspective of the traditional model which considers PRT and MT separately as well as from the perspective of the 2001 AASHTO model, which is based on gap acceptance. The accepted time gap is measured from the moment of perceptible movement of the vehicle, that is, after the PRT is finished. Thus time gap measures do not include PRT.

The ISD guideline below applies to crossing and turning maneuvers from a minor road (Cases IIIA, B, C AASHTO Policy 1994, Cases C1 and C2 AASHTO Policy 2001).

Guidelines follow for ISD PRT, ISD MT and ISD Critical Gap.

INTERSECTION SIGHT DISTANCE: PERCEPTION REACTION TIME GUIDELINES

Under baseline conditions (based on Lerner et al., 1995) the median PRT is about 1.3 sec, and the 85th percentile PRT is about 2.0 sec. PRTs are longer for:

- Younger drivers (by about 0.2 sec)
- Female drivers (but difference is mainly in daytime)
- Drivers using standard transmissions (by 0.06 to 0.38 sec depending on age)
- Under daytime conditions

Fewer night sessions than day sessions were run when it became apparent that day values were higher than night values.

Under unfavorable conditions: PRT may be lengthened.

- Turning right through the minor angle of skew intersection
- Crossing or turning at an intersection on a horizontal curve where the main road curves behind the driver
- Crossing at an offset intersection

In the first case, drivers must turn their heads through a greater angle to assess the presence of oncoming vehicles. In the second case the assessment of the acceptability of the gap may take longer due to the greater complexity of the geometry.

INTERSECTION SIGHT DISTANCE: MANEUVER TIME GUIDELINES

Under baseline conditions: The 85th percentile value for the time from initiation of the maneuver to where the vehicle is oriented parallel with the roadway is about 6.3 sec.

- Turning from right angle intersection
- Turning through the major angle of skew intersection

Under unfavorable conditions, such as the following, MT may be lengthened:

- Turning right through the minor angle of skew intersection
- Crossing or turning:
  - At an intersection on a horizontal curve where the main road curves behind the driver
  - On an upgrade
  - On wet or slippery pavement
  - In trucks
- Crossing at an offset intersection

The first condition is unfavorable because drivers must turn through a greater angle to fully complete the turn than is the case at a right-angled intersection. This is also true when a driver turns on a curve where the main road curves behind him or her. On an upgrade, on wet or slippery pavement, and for trucks, acceleration is likely to be slower, increasing MT. At an offset intersection, crossing includes two turns, increasing MT.

MT can be affected slightly (< 0.4 sec) by the following driver factors:

- Age and gender

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Figure. Static or dynamic illustrations showing turning through major and minor angles of skewed intersection

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INTERSECTION SIGHT DISTANCE: TIME GAP GUIDELINE

Under baseline conditions: The 85^{th} percentile gap accepted by left turning passenger car drivers, including substantial numbers of older drivers, is 11 sec. This is more than a 50^{th} percentile gap for single unit trucks and close to a 50^{th} percentile gap for double unit trucks.

- Turning left at right angle intersection
- Turning through the major angle of skew intersection

These values apply to posted or advisory speeds ranging from 56 to 72 km/h (35 to 55 mph), major road traffic volumes ranging from 1,750 to 13,500 and minor road volumes from 2000 to 6600 AADT. At higher volumes accepted gaps will be shorter as drivers feel pressured to turn when others are waiting.

Under unfavorable conditions: accepted gaps may be longer.

- Trucks turning
- Turning right through the minor angle of skew intersection
- Crossing or turning at an intersection on a horizontal curve
- Crossing at an offset intersection

Single unit trucks require on average 2.6 sec, and double unit trucks, 4.0 sec gaps for left turns than passenger car drivers. At intersections with “difficult” geometry (e.g. offset or curve), the best estimate on the basis of very limited data is as much as 1-2 sec addition gap required for passenger car drivers. When drivers must make a right turn through the minor angle of a skew intersection, their major search is to the left, which requires a more extensive head turn, and which would be expected to lengthen PRT and therefore the accepted gap.

Passenger car critical gaps for right turns are approximately 1.7 sec shorter than for left turns. On a multilane situation, a 0.7 second adjustment per additional lane in the critical gap size should be made for right turns, 0.4 seconds for left turns and 0.5 seconds for crossing maneuvers. In other words, for a three-lane crossing and a right turning passenger car driver, the critical gap would be 11 sec (for 85^{th} percentile left turning passenger car driver for a single lane in each direction) -1.7 sec (to account for right turn) -2 x 0.7 sec (to account for two additional lanes to cross). For intersections on a grade, critical gaps are longer by 0.1 second per percent grade for right turns, and 0.2 seconds per percent grade for left turns or crossing maneuvers. Accepted gaps for older drivers average about 1 sec longer than those for younger drivers. The accepted gap may also be lengthened by the following factors:

- High workload (e.g. multiple lanes to cross and therefore more than one oncoming vehicle to consider, several signs to be read, entrances and exits in area of influence of the intersection)

Because ISD based on time gaps includes assumptions about speed adjustments made by the major-road driver, additional distance may be required in situations where the approaching driver may not slow sufficiently. An approaching major-road driver may not slow sufficiently because recognition of the conflict is delayed or because of aggressive driving. Consider additional sight distance:

  - Where the major road driver is busy with complex signing, lane drops, or other high-workload demands prior to the intersection in question
  - Where traffic conditions or site history suggest aggressive driving and driver unwillingness to accommodate entering traffic

5.2.2.3 Basis/Rationale ISD PRT, MT and Critical Gap

The separate components of driver behavior on which ISD depends are difficult to define precisely because drivers generally start the search process while stopping at an intersection and continue their search as they move forward, ready to abandon the maneuver. Thus PRT overlaps MT; it is not a serial process when the driver is stopped as had been traditionally defined by AASHTO. A gap acceptance model, in which PRT and MT are considered as a whole, and search may begin before the driver had stopped, better matches the reality of driver behavior. The critical gap is that gap that drivers accept 50% of the time.

Key studies of ISD include:

- Naturalistic observations of gap-acceptance for truck and passenger car drivers at six intersections (Fitzpatrick, 1991)
- Measurement of PRT and MT at 14 intersections for 96 drivers (33 aged 20-40, 35 aged 65-69 and 34 aged 70+); measurement of critical gap and lag that subjects estimated they would accept (52 aged 20-40, 39 aged 65-69 and 47 aged 70+) (Lerner et al., 1995)
- Naturalistic observations of gap-acceptance for passenger car drivers at 44 intersections (Kyte et al., 1996) (in Harwood et al., 1996)
- Naturalistic observations of gap-acceptance for truck and passenger car drivers at 13 stop-controlled intersections (Harwood, Mason, Brydia, Pietrucha, & Gittings, 1996)

ISD PRT

The Lerner et al. (1995) study involved 96 drivers (33 aged 20-40, 35 aged 65-69 and 34 aged 70+) at 14 sites, of which 11 were used for both day and nighttime data collection. The intersection sites varied in terms of cross-section, geometric layout (right-angle vs. skew) and posted speed, and in the maneuver required of the driver(left turn, right turn, through).

Drivers were observed while using their own vehicles in an on-road study. Drivers were occupied by having to make a rating while stopped at the intersection, before crossing it, preventing them from starting the PRT process while they were stopping. (Other studies show that drivers typically start the search process within the last few seconds as they approach a stop sign.)

PRT and MT were recorded in response to gaps that were accepted. Median PRT was about 1.3 sec, with an 85th percentile PRT of 2.0 sec. PRTs were longer for:

- Younger drivers (by about 0.2 sec)
- Female drivers (but difference is mainly in daytime)
- With standard transmissions (by 0.06 to 0.38 sec depending on age)
- Under daytime conditions

Fewer night sessions than day sessions were run when it became apparent that day values were higher than night values.

PRT may be lengthened at skew or offset intersections. In the first case, drivers must turn their heads through a greater angle to assess the presence of oncoming vehicles. In the second case the assessment of the acceptability of the gap may take longer due to the greater complexity of the geometry. No studies were found of this issue.

ISD MT

MT for turning movements was determined to have ended at the point where the driver's vehicle was oriented parallel to the major roadway (as opposed to the AASHTO definition of the end of the maneuver being when the driver has reached 85% of the major road speed). The 85th percentile value for MT was 6.3 sec. The 50th percentile value was 5 sec. Longest maneuver times were for older females; the average of the 65-69 and 70+ females was about ¼ sec longer than the average of the 20-40 year old group. Overall there was little difference between daytime and nighttime.

ISD TIME GAP

The beginning of measurement of the accepted gap is the point at which drivers have completed their PRT and have decided to accept the gap and their vehicle can be perceived to be moving forward. When drivers detect gap of sufficient length to accommodate their estimated MT, without requiring substantial braking from the oncoming driver, they pull out. A number of studies have made measures of critical gaps. Half of drivers accept a gap of this length when it is presented, while half reject this gap size. Below we consider not only critical gap, but the 85th percentile gap, that is, the gap accepted by 85% of drivers when it is presented.

An early study of gap acceptance by Ebbesen et al. involved 2000 observations of left turning vehicles at three different T-intersections, with mean velocities of 40 km/h (25 mph), 61 km/h (38 mph) and 72 km/h (45 mph) as well as at a T intersection where there was considerable variability in velocities of vehicles on the main road (Ebbesen, Parker, & Konecni, 1977). As found by Lerner et al. (1995) and Harwood et al. (1996) in later studies, the critical gap was the same no matter what the speed of vehicles on the cross-road. When three different intersections were compared, each with different speeds for the mainline traffic, the critical gap accepted by left turning traffic was the same - 7.25 seconds.

Drivers should require longer gaps at higher speed intersections because they will take longer to bring their speed up to that of the traffic stream. However, it appears that drivers do not estimate their own time requirements well, thereby forcing the following driver to slow. The impact of this underestimation may well be greater at higher speeds.

Kyte et al. (unpublished, cited by Harwood et al., 1996) measured critical gaps in the field for passenger cars at 44 two-way stop-controlled intersections. They determined that the critical gap for right turns from a minor road was 6.2 seconds, and for left turns, 7.1 seconds. They further determined that, in a multilane situation, a 0.7 second adjustment in the critical gap size should be made for right turns, 0.4 seconds for left turns and 0.5 seconds for crossing maneuvers. Finally, through statistical analysis, they determined that critical gaps were longer by 0.1 second per percent grade for right turns, and 0.2 seconds per percent grade for left turns or crossing maneuvers. Kyte's results indicate that drivers are sensitive to the need to allow extra time due to crossing more lanes and due to slower acceleration on an upgrade.

Lerner et al. (1995) assessed both lags and gaps. In the case of a gap, the waiting driver is making a judgment about the gap between two moving vehicles. In the case of a lag, the waiting driver is making a judgment about the arrival time on a single vehicle. Subjects in a vehicle stopped on a minor road used a button to indicate whether it was safe to pull out to make a specific maneuver (right turn, left turn, through maneuver in the presence of a gap or a lag). No actual maneuvers were made.

For passenger vehicles, the average critical gap was 7 sec., and the 85th percentile was 11 sec. Longer gaps were accepted:

- By older drivers (overall oldest drivers required 1.1 more seconds than youngest drivers)

- By female drivers (accept gaps that are 1 sec longer than those accepted by male drivers, but difference is mainly in daytime)
- For left and right maneuvers as compared with through maneuvers
- Under daytime conditions (by about 1.5 sec)

With respect to gaps and lags, Lerner et al. (1995) found that lags accepted were shorter than gaps accepted (5.3 sec on average, vs. 7 sec for a gap).

The Harwood et al. (1996) study used naturalistic observation involving videotaping to measure gap-acceptance behavior of drivers at 13 stop-controlled intersections in 3 states as they made left turns and right turns. The study sites included 5 intersections with 3 legs and 8 intersections with 4 legs. Only right-angle intersections were considered. The major road approaches had posted speed limits or advisory speeds ranging from 56 to 72 km/h (35 to 55 mph). All study sites had good safety records. A total of 6243 acceptance/rejection decisions provided data on critical gap for right turn maneuvers; 3526 acceptance/rejection decisions provide data on critical gap for left turn maneuvers.

The Table below shows the results indicating that drivers of trucks require longer gaps, in both left and right turn situations, to enter a major road as compared to passenger vehicles.

Critical Gaps Derived from Field Data for Right and Left Turns on a Major Road

Vehicle Type	Critical gap (sec)	
	Raff method	**Logistic regression**
RIGHT-TURN MANEUVERS		
Passenger car	6.3	6.5
Single-unit truck	8.4	9.5
Combination truck	10.7	11.3
LEFT-TURN MANEUVERS		
Passenger car	8.0	8.2[a]
Single-unit truck	9.8	10.8
Combination truck	10.0	12.2

[a] Based on an average giving equal weight to each site.

(from Harwood et al., 1996)

The current AASHTO value of a 7.5 sec time gap for left turning and 6.5 sec for right turning drivers turning in front of passenger cars was developed based on the Harwood et al. study. As shown above, the critical gap for left turns by passenger cars was 8.0 sec. However, when drivers accept gaps less than 10 sec., the major road vehicle typically slows to accommodate the entering vehicle. The median speed reduction of major road vehicles was 31%. This means that an 8.0 sec gap is equivalent to a 7.5 sec gap at the initial speed.

The 50th percentile gap, rather than a higher percentile, was used on the basis it is the responsibility of the major road vehicle to accommodate the entering vehicle, and the field studies showing that major road drivers can do so by reducing their speeds by " 15 to 50% using very modest deceleration rates."

However, the findings by Lerner et al. (1995) suggest that some groups of drivers (e.g. older drivers and female drivers in daytime, and possibly novice drivers, though no data are available on this, as well as drivers of vehicles with standard transmissions) will prefer longer gaps than the average driver. If sight distance is set at the value that is accepted 50% of the time by a large group of drivers, it may not be that desired by a group of older drivers, whose maneuver times are longer than those for young drivers, and who would willing have pull out onto a major road with a gap of only 7.5 sec. Furthermore, the critical gaps accepted by drivers of single or double unit left turning trucks are substantially longer (by 1.6-1.8 sec for single unit trucks, and by 2 sec for double unit trucks) than that accepted by passenger car drivers, because the larger vehicles requiring more maneuver time and much longer to reach traffic speeds. When trucks turn onto a rural highway, especially at night, the major road driver may not appreciate until they are too close, just how much more slowly the truck is moving. To accommodate these drivers, the gap accepted 85% of the time by passenger cars, that is, 11 sec, is proposed based on the Lerner et al. study. The Lerner et al. study is weighted more heavily towards older drivers than the Harwood et al. study would have been, based as it was on the drivers on the road at the time the study was conducted. Another argument for the 11 sec value, is that it exceeds slightly the critical gap for left-turning straight trucks, measured by the logistic regression method, and is approximately equal the critical gap for left-turning double unit trucks, when the value measured by the logistic regression (12.2 sec) and that measured by the Raff method (10.0 sec) are averaged. The use of an 85th percentile value is especially important on high volume roads where the chances of a vehicle appearing coincident with the driver pulling out are high and on roads that are used by trucks, especially those with trailers.

Another issue which is important but has not yet been considered in the ISD Time Gap studies is the safety margin in relation to intersection sight distance. As will be discussed in Section 5.2.4.4, as available passing sight distance increased, there was no consistent effect on judgment time or on time in the opposing lane, but the time safety margin did increase in proportion to available sight distance. In those situations where gaps are hard to judge (see examples below) gaps accepted may be more variable, and longer sight distances would allow for errors in judgment by allowing a longer safety time margin once the gap was accepted. It should be noted though, that there are many reasons for the right-angle intersection crashes which result from errors in gap acceptance; more sight distance would not necessarily eliminate all or even most of such crashes.

One study of critical gaps included a site with difficult geometry compared to the other five right angle intersections. This was an offset intersection (by 1.5 m. (5 ft)) on a horizontal curve (Fitzpatrick,1991). Depending on the method used to analyze the critical gap (Greenshields, Raff or logit), the critical gaps at this intersection were determined to be 1 to 2 seconds greater than the 6.5-second critical gap determined for passenger cars at other intersections. There may be two different contributing factors to the longer critical gap. First, while waiting to pull out from an intersection, drivers attempt to estimate the time of arrival of oncoming vehicles based on changes in the apparent size of the approaching vehicle. When an intersection is on a horizontal curve, the apparent size of the approaching vehicle changes, both due to decreasing distance to the intersection and due to the curving road path. This likely increases the difficulty of deciding whether or not a gap is acceptable and may increase accepted gap size. Second, the presence of the offset increases the difficulty of negotiating the intersection, which likely increases the critical gap.

When drivers must make a right turn through the minor angle of a skew intersection, their major search is to the left, which requires a more extensive head turn, and which would be expected to lengthen PRT and therefore the accepted gap. No studies were found of critical gaps at skew intersections.

SUMMARY: ISD
Cases C1 and C2

PRT Factors	PRT	MT Factors	MT	CRIT GAP Factors	85th Accepted GAP	AASHTO
Driver age, gender Standard transmissions Day vs. night Clutter, complexity	2.0 sec	Driver age Vehicle type Intersection geometry No. of lanes Right vs. left turns Grade	6.3 sec	Driver age Vehicle type Intersection geometry No. of lanes Right vs. left turns Grade	11 sec (left)	8.0 (left)

5.2.3 Decision Sight Distance

5.2.3.1 DEFINITION DSD

Decision sight distance is the sight distance that should allow drivers to detect an unexpected or difficult-to-perceive information source or condition, recognize the condition or its potential threat, select an appropriate speed and path, and initiate and complete the maneuver safely and efficiently (Alexander & Lunenfeld, 1975).

Five maneuver types are defined by AASHTO (2001):

- Avoidance Maneuver A: Stop on rural road: t = 3.0 s
- Avoidance Maneuver B: Stop on urban road: t = 9.1 s
- Avoidance Maneuver C: Speed/path/direction change on rural road: t varies between 10.2 and 11.2 s
- Avoidance Maneuver D: Speed/path/direction change on suburban road: t varies between 12.1 and 12.9 s
- Avoidance Maneuver E: Speed/path/direction change on urban road: t varies between 14.0 and 14.5 s

The t values enumerated above are pre-maneuver values, that is pre-braking in the case of maneuvers A and B, and pre lane-changing in the case of maneuvers C, D and E. These t values are PRT values. More PRT is allotted on urban roads than on rural roads. Urban roads generally involve higher traffic levels and greater visual complexity of the driving environment.

Avoidance maneuvers A and B involve the driver recognizing the roadway or traffic situation, identifying alternative maneuvers and comfortably braking to a stop. Avoidance maneuvers C, D and E involve the driver recognizing the roadway or traffic situation, identifying alternative maneuvers and making a lane change. Lane changes are assumed to require 3.5 to 4.5 sec, with decreasing time required at increasing speeds.

In this chapter we consider only avoidance maneuvers C, D and E. Avoidance maneuvers A and B will be considered in Chapter X: Intersections. **[Chapter X]**

The decision sight distance for avoidance maneuvers C, D and E are determined as:

Metric	US Customary
$d = 0.278Vt_{PRT+MT}$	$d = 1.47Vt_{PRT+MT}$
where: t_{PRT+MT} = pre-speed/path/direction change maneuver time: 10.2 – 11.2 sec rural 12.1 – 12.9 sec suburban 14.0 – 14.5 sec urban V = design speed, km/h	where: t_{PRT+MT} = pre-speed/path/direction change maneuver time: 10.2 – 11.2 sec rural 12.1 – 12.9 sec suburban 14.0 – 14.5 sec urban V = design speed, mph

In computing and measuring DSD the same 1.08 m (3.5 ft.) eye-height and 0.6 m (2.0 ft) object height are assumed as for SSD.

5.2.3.2 HIGH PRIORITY CONSIDERATIONS

Examples of traffic control devices and road geometric elements which are high priority with respect to the need to apply or to consider decision sight distance so that drivers can change lanes comfortably include:

- A guide sign
- Lane markings indicating a change in cross-section
- Overhead lane arrows
- Traffic signals
- The paved area of an intersection for:
    - First intersection in a sequence
    - Isolated rural intersections
- A change in cross-section (2 lane to 4 lane, 4 lane to 2 lane, passing lane, climbing lane, lane drop, optional lane split, deceleration lane, channelization).

The presence of visual complexity combined with any of the above elements increases the need for consideration of decision sight distance. In addition, the presence of truck traffic which can block the view of any of the above traffic control devices and road geometric elements may be compensated for by increased sight distance, which allows more opportunities for drivers to see the item of interest.

5.2.3.3 GUIDELINE FOR DSD MANUEVERS C, D & E

DSD PRT MANUEVERS C, D & E

With respect to roadway decision points such as lane drops, turning points or merges, PRT includes time to detect the roadway change, recognize the need to make a decision, make the decision and initiate the response. The response may include searching for a gap in traffic in order to make a lane change and/or speed reduction for turns. Where lane changes are required, PRT includes time for drivers to search for a gap in traffic.

Depending on the site, there are a number of potential cues that a decision point is ahead: signs, markings, traffic patterns, parked vehicles etc. and site geometry (e.g. lane split). The physical feature that the driver must respond to is the gore at the lane drop or split. Signs generally are visible first, followed by markings, and then the physical gore itself.

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Figure showing favorable and unfavorable conditions for DSD

Animation illustrating examples of baseline and unfavorable conditions, including high (urban expressway, closely spaced exits and multiple guide signs at night, with dense but free-flow traffic) and low workload
(rural highway, daytime, little traffic) situations.

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DECISION SIGHT DISTANCE: PERCEPTION REACTION TIME – MANUEVERS C, D AND E GUIDELINES

Under baseline conditions it can be assumed that the driver is responding to either signs or markings. Under baseline conditions most drivers (85%) will be able to determine that there is a decision point ahead, locate a suitable gap in traffic and initiate a lane change within a PRT of 7.8 sec. In baseline conditions PRT can be measured from the point at which the markings for the gore or turn lane are first visible at night.

Baseline conditions assume:

- Visually uncluttered environment
- Conspicuous, easily understood signs, placed overhead or on the right
- Conspicuous markings accompanied by PRPMs in the gore area for visibility in rain
- Minimal view blockage of signs, markings and gore due to traffic
- Unfamiliar driver

Unfavorable conditions assume:

- Poor marking and signing
- Deceptive appearance of site
- Features that violate driver expectancies (e.g. freeway left exit, add-drop lane, first signalized intersection)

Under these conditions it is assumed that some or many drivers will miss the sign and marking cues and respond to the last available cue, which is the physical gore. Most drivers (85%) will be able to detect the decision point, locate a suitable gap in traffic and initiate a lane change within a PRT of 20 seconds **measured from the physical gore**.

Situational variables that may affect PRT are:

- High driver workload due to concurrent tasks (e.g. traffic merging, presence of guide, warning or regulatory signs unrelated to the lane drop)
- Dense traffic
- Truck traffic which intermittently blocks the view
- Off roadway clutter which can distract drivers
- Poor weather which increases driver workload and makes cues (especially markings) less conspicuous

These variables can contribute to delayed recognition of signs, markings and the presence of the physical gore. In the worst case, the gore will be the cue, and drivers' response will be sufficiently delayed that they are unable to complete a lane change before reaching it. DSD PRT has not yet been measured under all these conditions. The worst 85^{th} percentile value PRT found in experimental studies at a poorly marked freeway site was 23 seconds.

DECISION SIGHT DISTANCE: MANEUVER TIME – MANUEVERS C, D AND E GUIDELINES

Under baseline conditions: When MT was measured from the gore, only for those drivers who did not start to respond until the gore was visible, 85th percentile MTs were 6.4 sec overall (urban and freeway sites combined), with longer MTs by 1.2 – 2.0 sec for urban sites.

- A single lane change

Data suggests that maneuver times are 0.5 sec longer for left lane as compared to right lane merges.

Under unfavorable conditions: MT should be increased by 5 sec for each additional lane change in light traffic, and 7.2 sec for each additional lane change required in moderate or heavy traffic (726+ vehicles per lane per hour).

- More than one lane change
- Dense traffic

MT can be decreased by the following driver factors:

- Age
- Urgency

The closer to the physical gore at the point at which the driver realizes the need for a lane change, the more quickly it will be accomplished. In some situations older drivers have faster MT's to compensate for delayed recognition of cues such as signs and markings.

5.2.3.4 BASIS/RATIONALE FOR DSD AVOIDANCE MANEUVERS C, D & E GUIDELINE

DSD PRT and MT are difficult to define exactly because drivers may respond to one of several cues (signs, markings or site geometry), and may find it difficult to report recognizing the situation before they start responding to it. Furthermore, studies of DSD have examined what drivers do in specific situations, but without determining whether the driver was able to respond comfortably, or was able to respond just in time. The longer the sight distance drivers have available, generally the longer their PRTs and MTs will be, because there is a lack of urgency. With shorter and shorter sight distances, drivers will respond more quickly, getting to the point where the lane change in no longer comfortable, and some drivers do not make it in time. This point has yet to be determined in an on-road study.

Key studies of DSD include:

- Measurement of PRT and MT for 19 drivers (5 aged 16-39, 12 aged 40-59, and 3 aged 60 or older) at 6 freeway sites, including 4 lane drop exits, a mainline lane drop, a lane split, as well as at 2 sites with lane reductions prior to intersections (McGee, Moore, Knapp, & Sanders, 1978)

- Measurement of PRT and MT for 98 drivers (28 aged 20 – 40, 35 aged 65 – 69 and 35 aged 70+) at 11 sites: 2 freeway lane drop exits, 3 mainline lane drops, 4 arterial turn lanes, one arterial lane drop due to parking, and one complex intersection (Lerner et al., 1995).

There is an important methodological difference between these studies which affects their interpretation. In the McGee et al. (1978) study, detection and recognition time was measured between the point that the physical gore was in view to the experimenter and the point that drivers indicated that they needed to change lanes or reduce speed to stay on course. Decision and response time was measured as the time elapsed between the driver recognition of the need to change lanes and the maneuver being initiated. In approximately half the trials, signs and markings allowed the driver to start responding before the physical gore was in view, leading to PRTs of 0 in response to the gore; these data were excluded from calculations of PRT and maneuver time.

In contrast to the methodology of McGee et al., the Lerner et al. (1995) study first established the point at which an experimenter could first sight each potential cue (sign, marking and gore). Then PRT was measured from this point to the point at which drivers reported sighting of the first cue (sign, marking or gore) to the upcoming lane drop or arterial turn lane. Thus PRT is based more precisely on the particular cue used by the driver, but is not necessarily related to when the gore or decision point was visible.

DSD PRT MANUEVERS C, D AND E

Based only on subjects (approximately 50%) who signaled their detection of the need to change lanes after the gore became visible, McGee at al. (1978) found that mean PRT (detection and recognition plus decision and response initiation time) was 10.5 sec. Based on available information, the 85th percentile PRT value is estimated to be about 20 sec. Since the McGee et al. data are based only on drivers who identified the need to change lanes after the gore was visible, they are based on PRT with respect to the physical gore. Since only 50% of drivers responded this late, the mean value of 10.5 sec actually encompasses the majority (about 75%) of subjects.

The site with the longest PRT, with an 85th percentile value of 22.5 sec, was a lane drop exit with poor marking and signing. At this site one-third of drivers did not realize they were in an exit lane and drove on the shoulder until they realized they had passed the actual gore. Despite the fact that the available DSD was equivalent to 24 sec., because of the poor marking and signing, this DSD was insufficient to comfortably allow PRT and MT.

Lerner et al. (1995) found that at most sites, most drivers responded to signs. At freeway sites, the posted speed was 88 km/h (55 mph) and the signs were placed 214 m (687 ft) to 1600 m (5133 ft) from the physical gore. At the arterial sites, the posted speed was 64 km/h (40 mph) and signs were placed 92 m (295 ft) to 229 m (734 ft) from the intersection.

At 3 out of 6 arterial sites (2 arterial turn lanes and 1 complex intersection) drivers responded only to markings. At 1 of the 5 freeway lane drop sites only 1/3 of the drivers responded to signs; the rest responded to markings. At this site, in contrast to the other freeway lane drops, the signs were placed on the left.

Driver PRT depends in part on urgency. The longest PRTs were for the sites with signs farthest in advance of the lane drop (458 m [1500 ft] to 1600 m [5250 ft]), and the shortest for sites with signs closer to the lane drop (305 m [1000 ft], 214 m [700 ft]). Similarly PRTs were longer in daytime when cues could be seen further away as compared to at night. PRTs were also longer for young as compared to older drivers. This may have been because younger drivers were more likely than older drivers to use sign cues which are visible from a greater distance, as well as being further from the physical gore than are markings, allowing more time for the response.

At freeway sites, the 85th percentile values for daytime PRTs were similar for all three age groups (7.8 for 20 – 40 year olds, 7.6 for 65 – 69 year olds, and 7.8 for 70+ year olds). At arterial sites, the 85th percentile values for daytime PRTs were considerably shorter for the younger group (4.2 sec) than for the older groups (7.6 and 7.1 sec).

These values are all shorter than those measured by McGee et al. (1978). The reason is that the Lerner et al. values were measured in response to the cue actually used by the driver (sign, marking or gore) and not assumed to be in response to the gore. Sign and marking cues were visible before the gore.

Baseline Conditions

In baseline conditions, where signs and markings are conspicuous and easily understood, an 85th percentile PRT value of 7.8 sec is selected based on the longest PRTs, i.e., daytime values for freeway conditions for the oldest and youngest age groups (7.8 for 20 – 40 year olds, and 7.8 for 70+ year olds) in the Lerner et al. study. Most of these PRTs are relative to sign placement, however at some sites a large number of drivers used marking cues. Therefore a conservative approach is proposed whereby PRT is based on the visibility of the marking, rather than the sign cue.

Unfavorable Conditions

In unfavorable conditions, where signs and markings are inadequate (e.g. poor reflectivity) and the driver responds to the appearance of the physical gore, an 85th percentile PRT value of 15.4 sec is selected based on the 85th percentile values from approximately half of the McGee et al. subjects, who did not indicate detection of the upcoming lane change requirement until the physical gore was visible. For unfavorable conditions it is proposed that the PRT be based on the visibility of the physical gore.

DSD MT

Like PRT, driver MT depends in part on urgency. Lerner et al. (1995) found that the shortest MTs were at an arterial site where there were no marking or sign cues to the lane drop – only the presence of parked vehicles. MTs, like PRTs, were longer in daytime when cues could be seen further away as compared to at night. Unlike the case with PRTs, MTs were longer for older as compared to younger drivers.

Lerner et al. (1995) do not provide 85th percentile values for MT, but rather for the combination of PRT and MT. Times were longer for daytime than for nighttime. If PRT values are subtracted from the combination, then at freeway sites, 85th percentile daytime MTs were 8.7 sec for younger subjects and 10 and 11 sec for the two older groups.

At the arterial sites, the younger drivers also had shorter 85th percentile total time. If PRT values are subtracted from the combination, then the 85th percentile values for daytime MTs were 9.9 sec for the younger group, and 8.6 and 8.9 sec for the two older groups. The shorter maneuver times for the older groups (by 1 to 1.3 sec) may indicate a greater urgency by the time the maneuver was made. It must be noted that these times are not related to the distance from gore, but rather from the first cue identified by the driver, which might have been a sign, markings or in some cases the gore itself.

Based on McGee et al., 1978, the overall mean for maneuver time at freeway and arterial sites was 4.6 sec (st.dev. 1.7 sec). Based on the standard deviation, the 85th percentile MT was 6.4 sec. MTs were longer at lower speeds, and longest at the two urban intersection sites, where means were 5.8 and 6.6 sec, 1.2 – 2.0

sec longer than the overall mean. MTs were measured separately for left (4.7 sec) and right (4.2 sec) lane merges at a lane split.

The longer maneuver times measured by Lerner et al. may reflect less urgency than was the case for the McGee et al. subjects. This is because the only data used by McGee et al. to calculate MT are for subjects who did not indicate a need to respond until the gore was visible. This was likely many seconds after the signs and markings were visible.

A study by McNees of lane changing distances indicates that the time and distance required to move from the left to the right side of a multi-lane highways can be considerable (McNees, 1982). The amount of time and distance was recorded for 20 subjects driving an instrumented vehicle who maneuvered from the far left lane to the far right lane on three and four lane freeways in light (725 vehicles per hour or less), medium (726 – 1225 vehicles per hour) and heavy (> 1225 vehicles per hour) traffic. Subjects were asked to keep to the posted speed limit which was 88 km/h (55 mph). Distance was calculated according to the speed traveled and the time taken from signaling to turn from the left-most lane until all four wheels had crossed into the right-most lane.

The results are shown in the table below:

	Three lane maneuver			Four lane maneuver		
Traffic Condition	**N**	**Mean Distance m – (ft)**	**85th percentile distance m – (ft)**	**N**	**Mean Distance m - ft**	**85th percentile distance m – (ft)**
Light	56	282 (925)	367 (1204)	48	367 (1204)	488 (1600)
Medium	56	307 (1007)	405 (1329)	57	464 (1522)	587 (1925)
Heavy	59	305 (1001)	472 (1549)	63	419 (1375)	538 (1765)

The longest distance was required for 3 lane changes (4 lane maneuver) in moderate traffic. In heavy traffic, speeds were lower (13-27 km/h [8-17 mph]), so although more time was required, the distance required was less.

Assuming that subjects were traveling at the speed limit, and in light traffic, the 85th percentile time to complete three lane changes as compared to two lane changes was an additional 5 sec., and, in medium density traffic, 7.4 sec.

SUMMARY: DSD Avoidance Maneuvers C, D & E

PRT Factors	PRT	MT Factors	MT	AASHTO
Driver workload Urgency – sign, marking or physical gore as cue Poor visibility Expectancy violation	7.6-7.8 sec Measured from point sign or marking is visible 20 sec measured from gore	# lane changes Required Left lane vs. right lane merges Urban vs. freeway Age urgency	6.4 sec measured from gore	10.2 11.2 sec rural measured from gore 12.1-12.9 sec sub-urban measured from gore 14.0-14.5 sec urban measured from gore

5.2.4 Passing Sight Distance

5.2.4.1 DEFINITION

Passing sight distance is the length of the highway ahead necessary for one vehicle to pass another before meeting an opposing vehicle that might appear after the pass begins (ITS Traffic Engineering Handbook, Pline, 1999).

The AASHTO model is based on field studies conducted before 1958 (Hassan, Easa, & Abd El Halim, 1996) and assumes that once drivers begin to pass, they have no opportunity to abort it. The MUTCD guidelines for markings, on the other hand, assume that drivers can abort the pass, and the assumed required passing sight distance is much shorter.

PSD includes four components **[AASHTO, 2001, CH3]**:

- d_1, which is traversed during PRT and during the interval when the driver brings the vehicle from the trailing speed to the point of encroachment of the passing lane
- d_2, which is traversed while the passing vehicle occupies the passing lane
- d_3, which is the distance between the passing vehicle at the end of its maneuver and the opposing vehicle
- d_4, which is traversed by the opposing vehicle for two-thirds of the time the passing vehicle occupies the passing lane (i.e., 2/3 of d_2)

The distances for d_1 and d_2 are defined in AASHTO (2001) as shown below:

Metric	US Customary
$d_1 = 0.278t_i \left[v - m + \frac{at_i}{2} \right]$	$d_1 = 1.47t_i \left[v - m + \frac{at_i}{2} \right]$
where: t_i = time of initial maneuver, s a = average acceleration, km/h/s v = average speed of passing vehicle, km/h m = difference in speed of passed vehicle and passing vehicle, km/h	where: t_i = time of initial maneuver, s a = average acceleration, mph/s v = average speed of passing vehicle, mph m = difference in speed of passed vehicle and passing vehicle, mph

Metric	US Customary
$d_2 = 0.278vt_2$	$d_2 = 1.47vt_2$
where: t_2 = time passing vehicle occupies the left lane, s v = average speed of passing vehicle, km/h	where: t_2 = time passing vehicle occupies the left lane, s v = average speed of passing vehicle, mph

5.2.4.2 RELATED DESIGN/OPERATIONAL ISSUE

Required passing sight distance relates to vehicle characteristics, road grade, and vehicle speeds. It also relates to whether or not the pass is aborted. Required passing sight distance is shorter if consideration is given to the possibility that the pass can be aborted. When passes are aborted, shoulder characteristics are important, since one consequence, is a loss of control due to encountering a pavement edge drop-off.

PASSING SIGHT DISTANCE: PERCEPTION REACTION TIME GUIDELINES

Mean PRTs to initiate a pass, and measured from when passing sight distance was available until when the **right** tire crossed the centerline, have been found to vary from 3.6 to 6.0 sec., depending on the particular site on two lane rural highways. No information is available on subject variability, but 85th percentile PRTs will certainly exceed mean PRTs.

Just as ISD PRT is affected by age, gender, standard transmissions and day versus night conditions, PSD PRT may be as well. However no studies were found on this issue.

5.2.4.3 GUIDELINE

Just as a gap acceptance model is used for describing driver behavior for crossing intersections, such a model could be used for describing passing behavior. However studies have not yet been conducted using this approach. Consequently, PSD is considered with respect to PRT and MT, which assumes a serial process.

PASSING SIGHT DISTANCE: MANEUVER TTIME GUIDELINES

Under baseline conditions:

- Passenger vehicle passing single passenger vehicle

the 50th percentile time required for passing, and measured from when the **right front** tire crossed the centerline until the **right rear** tire crossed back into the driver's lane, was found to be 5.2 to 7.3 sec. depending on the site, with the longest time, by 1.3 sec, found for the site with a 7% grade.

In a study where the 50th percentile time required for passing was measured from when the **left front** tire crossed the centerline until the **left rear** tire crossed back into the driver's lane, values ranged from 13 to 14.5 sec.

85th percentile times would exceed 50th percentile times.

Under unfavorable conditions:

- Passenger vehicle passing multiple vehicles
- Passenger vehicle passing truck
- Truck passing other vehicle
- Passing occurring on an upgrade

the time required for passing, once PRT is completed will be longer.

MTs may be increased with driver age, however no data were found on this issue.

PASSING SIGHT DISTANCE: GAP TIME GUIDELINES

Based on one study at five sites, the average passing time gaps accepted ranged from 15.7 to 22.4 sec, increasing linearly with available passing sight distance. All passes were made in the absence of oncoming traffic. Based on two studies, there is no relation between time spent in the opposing lane and passing sight distance. The linear relationship between average passing time gap and available sight distance is due to longer time margins at the end of the pass as available passing sight distance increases. These ranged from 4 sec (284 m or 929 ft.) to 10 sec (416 m or 1363 ft or longer).

Limited passing opportunities may influence driver decision criteria. Drivers may accept smaller gaps and compensate with higher passing speeds, which could lead to vehicle control problems.

Drivers have difficulty accurately judging the speed of approaching vehicles. Poor gap acceptance decisions related to misjudging high-speed vehicles is not a sight distance problem and may not be improved by increased sight distance.

5.2.4.4 BASIS/RATIONALE FOR GUIDELINE

The AASHTO model for PSD is based on data for single passenger vehicles passing single passenger vehicles. It is further based on the assumption that once drivers begin to pass, they have no opportunity to abort the pass. The MUTCD guidelines for markings, on the other hand, assume that drivers can abort the pass, and the assumed required passing sight distance is much shorter (e.g. AASHTO (2000) Exhibit 3-6 indicates that when the speed of the passing vehicle is 40 km/h that the total passing sight distance is 160 m., compared to the MUTCD (2003) which indicates 140 m.). The discrepancy is much higher at higher speeds; when the speed of the passing vehicle is 120 km/h, the total passing sight distance calculated is 915 m as compared to the MUTCD (2000) minimum of 395 m. As reported in the Older Driver Design Guidelines (www.tfhrc.gov/humanfac/01103, “Weaver and Glennon (1972) reported that, in limited studies of short passing sections on main rural highways, most drivers do not complete a pass even within a 244 m. (800 ft) section; and the use of passing zones remains very low when their length is shorter than 274 m (900 ft).” (Weaver & Glennon, 1972).

A concern about the marked end of the passing zone is anecdotal evidence from a workshop on traffic safety (Smiley, 2004) that indicates drivers are uncertain about whether this is the last point at which a pass can be started or the point at which passes must be completed. The MUTCD assumes that the change from the dashed to solid means “do not start a pass and get back into the right lane if you are in the left lane.” This may be another reason contributing to the low use of passing sections.

A number of models of PSD have been developed that consider PSD requirements from the point of view of the minimum sight distance required at the critical point, namely that point where a driver requires as much sight distance to safely abort the maneuver as to complete it. Depending on the exact model assumptions, that point occurs when the two vehicles are abreast of one another A revised model which better matches field observations has been developed by Hassan et al. (1996).

It should be noted that head-on crashes related to passing maneuvers, though serious, are rare. Only 4.6% of head-on fatalities are related to passing. It is interesting however that the majority occur in marked passing lanes (Federal Highway Administration, 1994), suggesting that the discrepancy between AASHTO and the MUTCD as well as an understanding of the nature of passing zone crashes requires attention.

The primary cue that a driver uses to determine whether or not it is safe to initiate a pass is the size of the image of the oncoming vehicle. In a series of experiments on a road not open to the public, Farber and Silver examined judgments in an overtaking situation (Farber & Silver, 1967). They found that drivers could make reasonable estimates of the distance of an oncoming car but not of its speed. Judgments of distance were accurate within a 20% error or less, 95% of the time. Judgments of speed were much poorer. At the extremes of oncoming car speed used, the passing distance at 96 km/h (60 mph) was actually less than that at 48 km/h (30 mph), indicating that subjects were not at all able to discriminate between these extreme speeds. Staplin et al. found that this may be a more pronounced problem for older drivers (Staplin, Lococo, & Sim, 1993). In a field study where drivers indicated whether or not they would accept a gap for the purposes of turning left and the speed of the oncoming vehicle was 48 km/h or 96.5 km/h (30 mph and 60 mph), older drivers accepted gaps based on the distance at which the vehicle was seen rather than its speed. In contrast younger drivers accepted a gap that was 25 percent larger for the higher speed vehicle. Drivers' inaccurate estimates cannot be compensated for by increasing sight distance, but the difficulty of speed perception **[Section 4.6]** can explain some crashes. Large vehicles may be especially susceptible to misjudgment. Crashes due to underestimating the available maneuver time when there is a high-speed approaching vehicle may be addressed through speed control measures or site factors that improve speed judgments **[Chapter X, Speed]**; it should not be assumed that greater sight distance will address this problem.

Drivers who pass may approach a slower vehicle and pass immediately (a flying pass), or may adopt a short headway and wait for an opportunity (a delayed pass). In the second case, more time for acceleration is required. In either case drivers may adopt a short headway just prior to the pass. A study on two-lane highways found that 40% of drivers following at short headways (1/2 sec or less) were doing so in anticipation of passing (Rajalin, Hassel, & Summala, 1997).

PSD PRT

A single study was found of PRT in the passing situation (Hostetter & Seguin, 1969). This study involved five sites on a two-lane highway in Pennsylvania and observations of 1462 passes. Subjects were not aware that their behavior was being measured. Impedance by an experimental vehicle was established prior to the subject vehicle entering the passing zone. Available sight distance varied from 283 m to 497 m (930 to 1630 ft). Subject drivers were impeded over distances of 1, 3 and 5 miles, by an experimental vehicle which traveled at 10, 20 or 30% of the subject vehicle's previously measured speed . Traffic volumes varied from 16 to 86 vehicle per hour. Observations of judgment time (time elapsed from availability of passing sight distance to front left wheels crossing the center line) were made. Opposing traffic was stopped out of view of the subject driver so that no opposing traffic was present during the passes. Mean judgment time was reported for each of five sites and varied from 3.6 to 6.0 sec. Standard deviations were not reported, however, based on studies of PRT in other situations, the 85th percentile PRT values would be expected to be on the order of 50% longer.

Just as ISD PRT is affected by age, gender, standard transmissions and day versus night conditions, PSD PRT may be as well. However no studies were found on this issue.

PSD MT

In the Hostetter and Seguin (1969) study cited above, movement time was measured from the point at which the right front tire of the subject vehicle crossed the center line to the point at which the right front tire of the subject vehicle crossed the center line back into the lane. Mean movement times are reported for each of the five sites and varied from 5.2 to 7.3 seconds. There was not a linear relationship with sight distance. The longest value, by 1.3 sec, was found for the site that had an approach gradient of 7% and a slight upgrade over the entire passing zone.

In a study at five sites on a recreational two-lane highway in Wisconsin, Kaub (1990) used field observers to record time in the opposing lane and type of pass (Kaub, 1990). Five types of passes were recorded: pass with no opposition (i.e. no opposition at the so-called “critical position” alongside the passed vehicle where the driver is assumed to make a pass/abort decision), pass with opposition: greater than 10 sec (i.e. at the point at the driver returned to his or her own lane there was greater than a 10 sec gap to the oncoming vehicle), between 5 and 10 sec, or less than 5 sec., pass with full abort, and multiple pass. Passing zone lengths varied from 549 m (1800 ft) to 2012 m (6600 ft) in length. Operating speed was approximately 96 km/h (60 mph). Observers recorded the time elapsed between the crossing of the centerline by the passing vehicle’s left front tire and the return of the vehicle’s left rear tire to the lane of origin, in other words to the first moment the opposing lane was encroached until the last. It should be noted that this definition of MT is different than that used by Hostetter and Seguin (1969), who measured from the crossing of the right tire. Given the definitions of MT, the MTs measured by Hostetter and Seguin (1969) would be expected to be a few seconds shorter than those measured by Kaub (1990), to allow for the time taken between the right and left tire crossing the centerline. A total of 4153 passing maneuvers were observed.

Under low traffic volumes (200-250 vehicles/hr in the major direction and 85 to 175 vehicles/hr in the minor direction), 65-75% of passes were attempted in the face of opposing traffic, 25-35% of passes were attempted in the presence of oncoming traffic, and 0.8% of passes were aborted. At high volumes (330-420 vehicles/hr in the major direction and 70 to 170 vehicles/hr in the minor direction), 51 to 76% of passes were made with no opposition, 26 – 50% of passes were in the presence of oncoming traffic and, 7.2 % of passes were aborted .

The average time in the opposing lane was 12.2 sec under low-traffic conditions and 11.3 sec with high traffic volumes. No standard deviations were provided. Depending on site and direction, times varied from a low of 7.98 sec to a high of 12.87 sec. There was no clear association between length of available passing lane and time spent in the opposing lane.

At a speed of 96 km/h (60 mph) the **average** times in the opposing lane are equivalent to distances of 325 m (1064 ft) for low-traffic and 301 m (986 ft.) for high traffic. This may be the reason for Weaver and Glennon’s (1972) observations that passing zones shorter than 274 m (900 ft) were seldom used.

Length of time spent in the passing lane was clearly related to the size of the time gap. Drivers returning to their own lane with more than 10 sec to spare averaged 12 sec in the opposing lane. Drivers returning with 5 to 10 sec to spare, averaged 8.7 sec and those with less than 5 sec to spare, 6.8 sec.

With respect to differences between older and younger drivers, studies find that preferred speed decreases and preferred headway increases with age (Evans & Wasielewski, 1983). Similarly accepted gaps in turning situations increase with age by about 1.2 sec (Lerner et al. 1995). Although no studies are available, it seems likely that passing time requirements for older drivers will be longer by virtue of both lower speeds and more conservative gap acceptance behavior. It also seems likely that older drivers are more likely to be driving the passed as opposed to the passing vehicle.

The time from when the vehicle wheels first encroach the opposing lane and ends when they last do so. Since drivers cannot accelerate until they enter the opposing lane, this definition of MT encompasses almost the entire maneuver. On this basis MT can be assumed to average 12.2 sec under lower volume situations (major flow 200-250 vph, minor flow 85-175 vph) and 11.3 sec under higher volume situations (major flow 330-420 vehicles/hr, minor flow 70 to 170 vehicles/hr). These are average values. Kaub does not report standard deviations which would allow 85th percentile values to be determined.

Multiple passes were found to occur during 6.4 to 21.4% of passes, depending on the direction and on the site. The likelihood of a multiple pass did not appear to be related to the length of the passing zone.

In higher flow conditions, time in the opposing lane averaged 0.9 sec less, and number of passes completed with the minimum safety margin of 5 sec or less increased from 6.3% to 9.2% Aborted passes increased from 0.75% to 7.2%.

MTs related to multiple passes and trucks will be longer than the times reported by Kaub (1990) which applied to single impeding passenger vehicles passed by other passenger vehicles.

Drivers do not typically accelerate at the maximum level their vehicles are capable of. Whether drivers accelerate closer to the maximum level to compensate in situations where geometric design factors slow acceleration is unknown. MT's may be longer in these situations. While driver factors would be expected to include age, given older driver preferences for lower speeds, they are more likely to be in the passed rather than the passing vehicle. However, as the population ages, increasingly older drivers will be passed by other older drivers who are likely to require longer MTs. No studies were found on this issue.

PSD TIME GAP

The Hostetter and Seguin (1969) study provided a measure of desired gap, in that the time safety margin when the pass was completed was also measured. The average passing time gaps accepted ranged from 15.7 to 22.4 sec, increasing linearly with available passing sight distance. All passes were made in the absence of oncoming traffic. Neither this study nor the Kaub (1990) study found any relation between time spent in the opposing lane and passing sight distance. The linear relationship between average passing time gap and available sight distance is due to longer time margins at the end of the pass as available passing sight distance increases. These safety time margins ranged from 4 sec (for passing sight distance of 284 m or 929 ft.) to 10 sec (for passing sight distance of 416 m or 1363 ft or longer).

SUMMARY: PSD

PRT Factors	Average PRT	MT Factors	Average MT	Average gap	AASHTO
Site geometry	3.6 – 6.0 sec	Site geometry	5,2-7.3 sec measured from right tire in lane 13 – 14 sec measured from left tire in lane	15.7 – 22.4 sec	14.4 sec at 40 km/h 27.5 sec at 120 km/h

5.3 Influence of Design on Speed

5.3.1 Background

The design of a road affects drivers' speeds through two major mechanisms. First, the design creates the driving task. Narrow lanes and sharp curves make the driving task more difficult and lead to reductions in speed. Secondly, drivers have expectations about the posted, and comfortable speeds, based on various combinations of design elements. Users of this guide should be aware that operating speeds may be very different from posted speed when the road message and the posted speed are at variance. Thus design sight distances may be more appropriately determined based on operating, not posted speed. Design elements that influence speed include the following:

- Lane width
- Alignment (horizontal and vertical)
- Road Surface
- Side Friction
- Shoulder width

5.3.2 Scope

This section is intended to address road features that influence driver speed choice and therefore impact required sight distances. There are a number of engineering studies which have used speed measurements made at numerous sites to develop models to predict speed based on road design. While it is not the intent of this chapter to critique these studies in detail, it does give an idea of the degree to which design features can affect driver speed choice. Operational features such as speed limit signs, lateral lane markings, post mounted delineators etc. may also affect speed. These are discussed in a later chapter on speed management **[Chapter X, Speed]**. For a more fundamental understanding of driver perception of speed the reader is referred to Chapter 4. **[Section 4.6]**

5.3.3 Speed and Lane Width

5.3.3.1 GUIDELINE: SPEED AND LANE WIDTH

SPEED AND LANE WIDTH

Increasing lane width from 3.3 to 3.8 m. is associated with an increase of 2.85 km/h in speed on high design standard two lane rural highways.

5.3.3.2 BASIS/RATIONALE FOR SPEED AND LANE WIDTH

Lane width influences speed because it influences the difficulty of the driving task. Narrower lanes require more frequent, smaller steering corrections (McLean & Hoffman, 1972), that is, more effort. Slowing down reduces the effort required.

In a 1990 report entitled "Behavioral Adaptations to Changes in the Road Transport System", an OECD Scientific Experts Group (OECD, 1990) reviewed impacts of lane width on driver behavior. Researchers consistently found a reduction in speed with decreases in lane width and vice versa.

A study of the effects of various geometric and environmental factors on the speeds for 2-lane rural highways (Yagar & Van Aerde, 1983) collected data for over 5000 5-minute periods at 35 locations. The most influential factors, in order of significance were as follows: legal speed limit, land use adjacent to the road, grade, access from other roads and lane width. Road curvature, the presence of an extra lane, sight distance, center line markings and lateral obstructions were not found to have a significant effect on speed. The lack of effect of some of these variables, especially road curvature, may be due to the fact that the roads examined had high design standards – gradients were less than 3% and radii of curvature were more than 1400 m. Other studies have found strong impacts of road curvature on speed, but that for curvature over 800 m. speeds on curves are essentially the same as those on tangents (Fitzpatrick, Carlson, Wooldridge, & Brewer, 2000).

Increasing lane width over a range from 3.3 to 3.8 m. was associated with an increase of 2.85 km/h in speed (Yagar and Van Aerde, 1983). The finding of very modest changes in speed associated with lane width is corroborated by more recent work (Fitzpatrick et al. 2000).

Although Yagar and Van Aerde found the legal speed limit had a strong effect, it must be remembered that legal speed limit is strongly associated with road design, and therefore the legal speed limit is going to be correlated with the presence of a specific bundle of road features. Another study by Parker looked at the effect of changing speed limits at 98 sites in 22 U.S. states (Parker, 1997). Depending on the site, speed limits were raised as much as 15 mph and lowered as much as 20 mph. At these sites it is important to note that the only change that was made was the speed limit sign. No other engineering or enforcement changes were made. The results showed minimal changes in speed. Furthermore the direction of the changes that did occur were not necessarily in the same direction as the speed change.

5.3.4 Speed and Alignment

5.3.4.1 GUIDELINE: SPEED AND ALIGNMENT

SPEED AND ALIGNMENT

Speed on curves can be reasonably accurately predicted using models based on radius, curve deflection angle and curve length. Once the curve radius exceeds 800 m., curves have similar speeds to tangents.
Speed on tangents is much more difficult to predict and is dependent on a wide array of road characteristics such as tangent length, radius of curve before and after the section, cross-section, grade, general terrain and sight distance. Posted speed is a better predictor of speed on urban arterial tangents than it is on highway tangents.

5.3.4.2 BASIS/RATIONALE FOR SPEED AND ALIGNMENT

Speed is strongly related to radius of curvature. Lamm and Choueiri and Krammes et al. (1995) developed models predicting speed based on radius, deflection angle and curve length. These models account for more than 80% of the variance in speed. In a study of speeds in 176 curves on rural 2 lane highways with posted speeds of 75 – 115 km/h, Fitzpatrick et al. (2000) found that the 85th percentile velocity was most strongly related to radius, and related, but less so, to grade and sight distance (R values .58 to .92). Once the curve radius exceeded 800 m., curves had similar speeds to tangents.

Speed on tangents is much more difficult to predict and is dependent on a wide array of road characteristics such as tangent length, radius of curve before and after the section, cross-section, grade, general terrain and sight distance. Models to predict operating speeds on tangent sections of two-lane rural highways were developed by Polus et al. (1999) based on speed measures at 162 sites with posted speeds varying from 75 to 115 km/h (equivalent to 50 to 70 mph). Models were developed for various combinations of radii and tangent length, and predicted between 20 and 84% of the variance. Studies on urban arterials find posted speed limit predicts 53% of the variance in speed.

5.3.5 Speed and Pavement Surface

5.3.5.1 GUIDELINE: SPEED AND PAVEMENT SURFACE

SPEED AND PAVEMENT SURFACE
Re-surfacing is associated with no or small increases in speed.

5.3.5.2 BASIS/RATIONALE FOR SPEED AND PAVEMENT SURFACE

One of the cues drivers use to estimate their own speed is noise level. Evans (1970) showed that when sound cues were removed through the use of earmuffs, drivers underestimated their actual speeds by 6 to 10 km/hr. Cooper (1980) showed that re-surfacing a road resulted in a speed increase of 2 km/h.

5.3.6 Speed and Side Friction

5.3.6.1 GUIDELINE: SPEED AND SIDE FRICTION

SPEED AND SIDE FRICTION
Elements close to the edge of the lane contribute to a reduction in driver speed. Results of one study of road sections posted at 50 km/h (31 mph) showed that 85th percentile speeds were 12 km/h (7.5 mph) lower in road sections with side friction due to the presence of pedestrians, bicyclists, parked vehicles etc.

5.3.6.2 BASIS/RATIONALE FOR SPEED AND SIDE FRICTION

Side friction refers to elements close to the edge of the lane such as pedestrians, bicyclists, parked vehicles, foliage, etc., which can strongly affect speed. This is because one of the major cues used by drivers is the streaming of information in peripheral vision. Side friction increases the stimulus in peripheral vision. In one study, drivers were asked to drive at 60 mph (96 km/h) with the speedometer covered. In an open-road situation, the average speed was 57 mph (91 km/h). After the same instructions, but along a tree-lined route, the average speed was 53 mph (85 km/h) (Shinar, McDowell, & Rockwell, 1977). The trees, close by, provided peripheral stimulation, giving a sense of higher speed.

The elements that create side friction, such as pedestrians, bicyclists, parked vehicles and landscaping also present various levels of hazard, likely influencing drivers to slow down to various degrees. In other words pedestrian presence close to the road edge is more likely to impact speed than landscaping close to the road edge.

Results of one study of 30 road sections posted at 50 km/h show that 85th percentile speeds were 62 km/h in road sections with little side friction (that is wide clear zones), but were 50 km/h in road sections with side friction due to the presence of pedestrians, bicyclists, parked vehicles etc. (Transport Canada, 1997).

5.4 Diagnosing Sight Distance Problems

The foregoing sections of this chapter have provided explicit guideline statements regarding human factors aspects of various sight distance concepts. However, for users to implement these guidelines in a practical sense, it is desirable to provide a procedure for their operational application. Therefore, this section comprises a hands-on tool whereby practitioners apply human factors techniques to analyze sight distance requirements at a selected highway location.

A starting point for development of the current procedure was a review of previously documented procedures for conducting on-site driving task analyses **[Ontario Traffic Manual, Appendix C, Positive Guidance Tool Kit]** that applied techniques such as commentary drive-thru procedures to generate check-list subjective scaled ratings of hazard severity and information load. The current in-situ sight distance diagnostic procedure includes application of previously available engineering tools, e.g., AASHTO analyses of geometric requirements and MUTCD traffic control device requirements, and augments these techniques with those sight distance concepts presented in Section 5.2 and 5.3 herein.

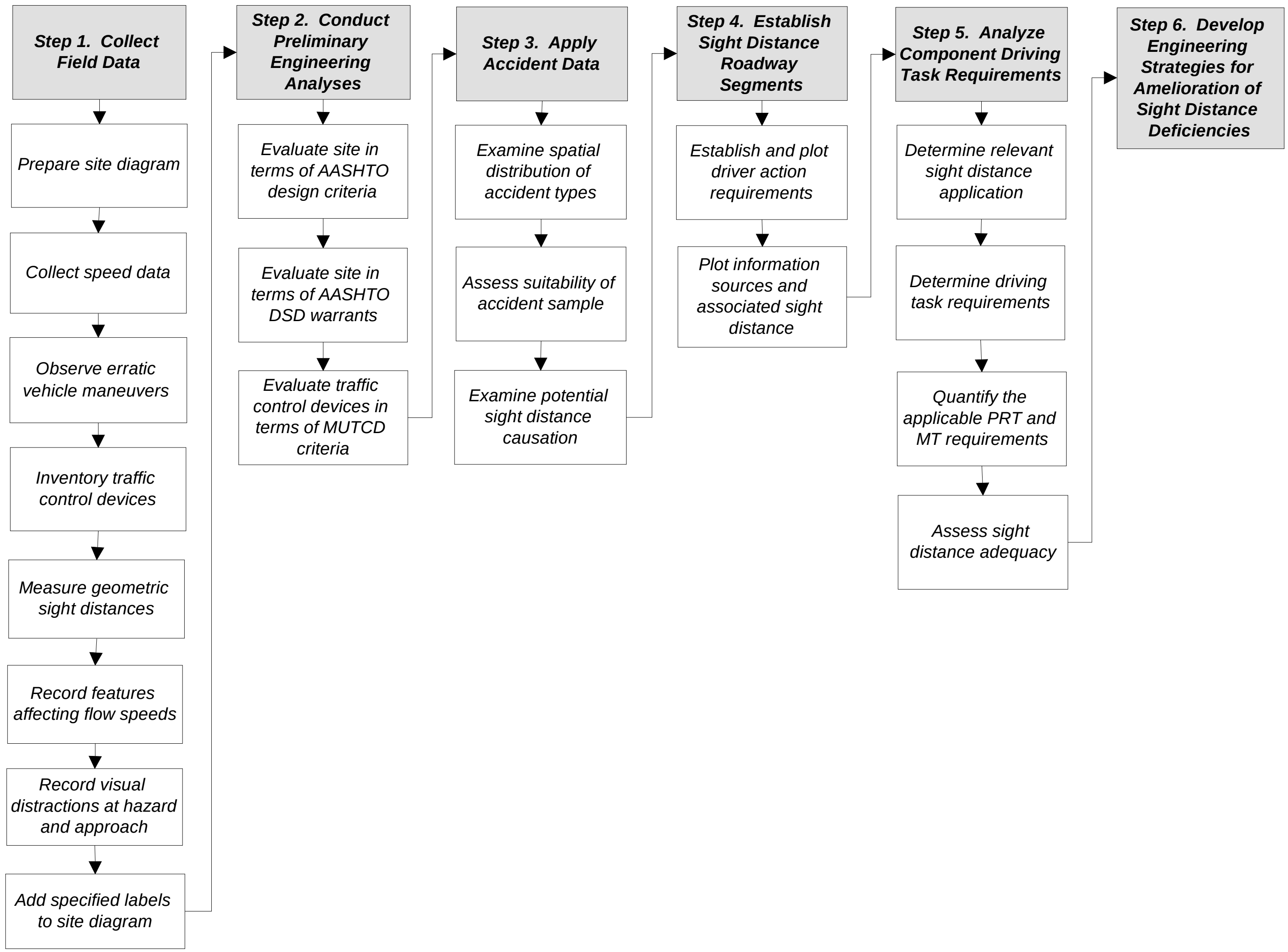
This sight distance diagnostic procedure consists of a systematic on-site investigation technique to evaluate the highway environment to support the concepts of interest, i.e., SSD, PSD, ISD, and DSD. The highway location is surveyed, diagrammed, and divided into component sections based on specific driving demands (e.g., requirement to perform a maneuver). Then each section is analyzed in terms of its suitability to support the required task (e.g., information provided to driver, allotted time to the complete required task). This procedure enables the practitioner to compare the *available* sight distance with the *required* sight distance to safely perform the driving task. Appendix A provides an example application of the procedure described in this section.

5.4.1 The Six-step Process

The procedure consists of six steps as follows:

1. Collect field data to describe roadway characteristics and other environmental factors affecting sight distance requirements and driver perception of a potential hazard.
2. Conduct engineering analyses applying traditional techniques, e.g., AASHTO design criteria and MUTCD compliance, to initially assess site characteristics or deficiencies.
3. Examine accident data and prepare collision diagram to seek possible association between safety and a sight distance problem.
4. Establish component roadway sections in which drivers respond to specific visual cues in order to avoid a hazard to initiate a maneuver.
5. Analyze driving task requirements (PRT and MT) and determine the adequacy of each component roadway section to support these requirements.
6. Develop engineering strategies for amelioration of sight distance deficiencies.

A flow diagram overview of the process is shown on the next page.



Flow diagram of six-step diagnostic process

***Step #1*: Collect Field Data**
This step involves making specific field measurements and observations. Data are to be gathered both at the location of a designated or possible hazard as well the approach roadway section immediately in advance of the hazard. Approach distances over which field measurements should be gathered are determined from Table 1 at the end of this step. Approach distances were derived from approximated perception-reaction and sign reading times applied to the designated operating speeds.

Step # 1A *Identify hazard and prepare site diagram*	
Procedure	Product/Application
The specific hazard location under investigation is identified and the approach roadway is diagrammed. Example of hazards requiring sight distance consideration and the associated sight distance concepts are as follows. • A hidden intersection **[SSD]** • An exit from a shopping mall in a heavily lit (or visually cluttered) setting **[DSD]** • A vehicle approaching an intersection **[ISD]** • An oncoming vehicle in a passing zone **[PSD]** Note distances from hazard to the following features: (1) traffic control devices, (2) intersecting driveway or roadways, and (3) sight distance obstructions.	NOTE: An example sketch is shown in the example which follows. **[Appendix A]** *Reference:* Lunenfeld, H. and Alexander, G. J., *A User's Guide to Positive Guidance* FHWA Report FHWA-SA-90-017, Federal Highway Administration, Washington, DC 1990

Step # 1B *Collect operating speed on approach*	
Procedure	Product/Application
Spot speeds for randomly selected vehicles are to be observed at a sufficient advance distance upstream from the hazard beyond which slowing in response to the hazard is expected. Candidate speed collection techniques are radar/laser detection, automated speed recorders, and manual timing. References noted below describe appropriate procedures to ensure random vehicle selection and suitable sample sizes. In the event that the approach roadway section is characterized by horizontal or vertical curvature, speed collection points should be selected so as to represent operational speeds at these locations.	The product of this step will be a statistical distribution of speeds from which means and/or percentile values will be applied to estimate vehicle speed for the approach roadway under study. *References:* Hanscom, F. R., Validation of a Non-automated Speed Data Collection Methodology. *Transportation Research Record 1111.* Transportation Research Board, National Research Council, Washington, D.C., 1987. Institute of Transportation Engineers, *Manual of Transportation Engineering Studies*, 2000

Step # 1C *Observe erratic vehicle maneuvers on approach*	
Procedure	Product/Application
Observations of vehicle movements should be considered in situations of sufficiently high traffic volumes to justify this type of study, e.g., 100 vph and above. Typical target vehicle behaviors indicative of a sight distance problem are sudden slowing (e.g., observable break light activation) and abrupt lane changes when these maneuvers are not induced by other vehicles in the traffic stream. A considerable literature base is available regarding the conduct and interpretation of "traffic conflicts" studies; however the reader is cautioned that traffic conflicts studies are limited to interactions between vehicles. A sight-distance induced erratic maneuver, on the other hand, can involve a single vehicle. Methodological literature addressing conflicts study is helpful with respect to observational techniques.	The outcome of this step should be insightful with respect to possible sight-distance induced vehicle behaviors. *References:* Parker, M.R. and Zeeger, C.V. *Traffic Conflicts for Safety and Operations.* FHWA-IP-88-026 (*Engineer's Guide)* and FHWA-IP-88-027 (*Observer's Guide)* Federal Highway Administration, Washington, DC Taylor, J.I., and Thompson, H.T., *Identification Of Hazardous Locations: A Users Manual,* FHWA-RD-77- 82, Federal Highway Administration, Washington, DC

Step # 1D *Inventory existing traffic control devices*	
Procedure	Product/Application
Document existing signs, signals, and pavement markings along with their respective distances from the hazard under study. The letter heights on signs need to be recorded.	The resulting device inventory will be subsequently applied in this diagnostic analysis to evaluate the suitability of provided information, as well as visual distractions and information processing demands on motorists as they approach the hazard under study.

Step # 1E *Measure existing geometric sight distances*	
Procedure	Product/Application
Existing geometric sight distance limitations along the approach to the hazard must be measured in accordance with AASHTO criteria. Specifically, sight distance observations should be made from an elevation above the pavement which equals the design driver eye height, i.e., 3.5 feet, to a point ahead that is 2.0 feet above the pavement.	This step will yield the length of specific roadway sub-sections along the approach in which drivers must observe and process available information, e.g., roadway features, other vehicles. *Reference:* (Pages 127 to 131) AASHTO, *A Policy on Geometric Design of Highways and Streets, 2001*

Step # 1F *Note factors affecting flow speeds*

Procedure	Product/Application
Certain roadway environmental features are known to affect drivers' selection of speed. Examples are pavement defects, narrow shoulder widths and protruding bridge piers, abutments, guardrail, median barriers, etc. Non-roadway features (e.g., pedestrians, parked vehicles) should also be noted.	Documentation and general awareness of these factors are important due to the fact that subsequent minor highway improvement projects may result in higher highway speeds, thus producing increased sight distance requirements.

Step # 1G *Note visual distractions at hazard location*

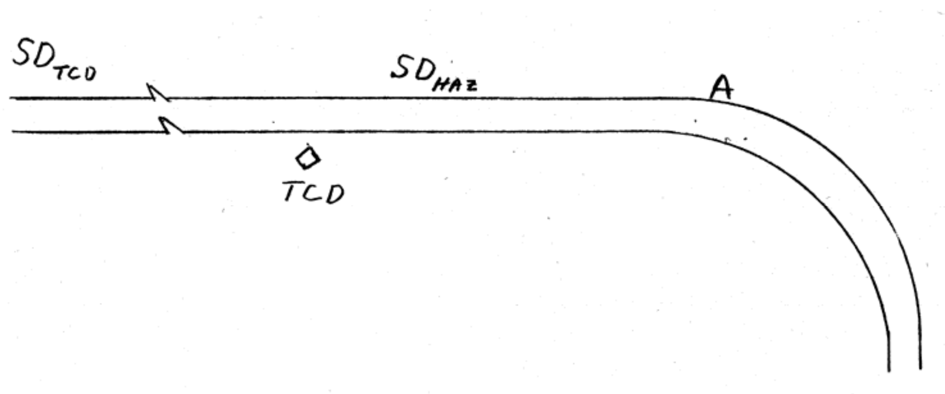
Procedure	Product/Application
Certain environmental conditions are known to produce "visual clutter", i.e., distractions which make hazards more difficult for drivers to perceive. Examples include: (1) off-roadway lighting, (2) commercial signing in driver field of view, (3) complex urban intersection designs, (4) high volumes of vehicular/pedestrian movement, and (5) proliferation of intersection traffic control devices. Observations should document drivers' field of view at SSD from hazard, e.g., see page 111 of AASHTO, *A Policy on Geometric Design of Highways and Streets, 2001*	This inventory of visual distractions will be subsequently applied in a human factors analysis to determine the applicable sight distance criterion (e.g., Decision Sight Distance, to address driver perception and information-processing time requirements at the hazard location.

Step # 1H *Note visual distractions along approach roadway*

Procedure	Product/Application
As in Step 1G above, visual environmental conditions along the approach to the hazard may also produce driver distractions. These need to be included in the field data collection process. Observations should document drivers' field of view at DSD from hazard, e.g., see page 116 of AASHTO, *A Policy on Geometric Design of Highways and Streets, 2001*	This inventory of visual distractions will be subsequently applied in a human factors analysis to determine the applicable sight distance criterion to address driver information processing time requirements on the approach to the hazard location.

Step # 1I *Label the diagram with specified symbols.*	
Procedure	Product/Application
$\Sigma\Delta_{HAZ}$ - *Sight distance to a potential hazard* – The point at which a location or object is first detectable to an approaching motorist. A - *Point of required action* – The location where an intended maneuver (e.g., hazard avoidance) is to be completed. $\Sigma\Delta_{TX\Delta}$ - *Sight distance to a traffic control device*– The point at which the device is first detectable to an approaching motorist. TXΔ- *Location of traffic control* device that warns of the hazard – measured as a distance from the location or object about which information is provided.	The inclusion of uniform symbols on the site diagram will facilitate the subsequent sight distance analysis.

A two-lane 55-mph roadway approaches a 35-mph curve.



Example Symbol Diagram

Approach Distance to Hazard, ft.			
Estimated Operational Speed, mph	Visually Cluttered Environment (A)	Visually Non-Cluttered Environment (B)	Additional, when TCDs Present (C)
25	360	180	95
30	440	220	110
40	580	290	150
50	730	370	185
60	880	440	220
70	1030	520	260

(A) Allows 10-second approach PIEV, per MUTCD for high judgment requirement
(B) Allows 5-second approach for 5-second visual scanning and PRT
(2) Allows an addition 2.5-second PRT for sign comprehension

Table 1 – Recommended approach distance to hazard for collection of field data.

***Step #2*: Conduct Preliminary Engineering Analyses**

This step involves the application of traditional traffic engineering techniques, e.g., AASHTO *Design Policy* geometric design criteria and Decision Sight Distance warrants, as a preliminary determinant of site deficiencies. In addition, the placement of traffic control devices needs to be examined in terms of MUTCD requirements.

Step #2A. *Examine Hazard Location with respect to AASHTO Design Criteria*	
Procedure	Product/Application
In order to ensure a valid engineering diagnosis of sight distance to a hazard, it is necessary to first assess whether the hazard location itself has any inherent design shortcomings. One geometric deficiency potentially associated with a hazard location might be roadside that fails to meet requirements of the AASHTO *Roadside Design Guide*. Other examples are (1) a high-accident intersection which may be deficient with respect to existing corner sight distance, (i.e., see pages 655 to 680 of AASHTO, *A Policy on Geometric Design of Highways and Streets, 2001*); and (2) in the case of a high incidence of run-off-road accidents, compare observed operational speeds (from Step 1A above) with the design speed based curve radius and superelevation and the curve under consideration, (e.g., see pages 131 to 168 of AASHTO, *A Policy on Geometric Design of Highways and Streets, 2001*)	The resulting analytical steps ensure that the hazard location itself is free of any inherent design shortcomings that have the potential for confounding the intended sight distance diagnosis.

Step #2B. *Examine Approach with respect to AASHTO Design Criteria*	
Procedure	Product/Application
As with the procedure noted in Step 2A, to ensure the integrity of the overall sight distance diagnosis, it is necessary to assess whether the approach to the hazard location has any inherent design shortcomings. (For example, a substandard lateral clearance to a roadside object along the approach may create a visual obstruction, thus producing an unintended sight distance limitation.) Likewise, crest vertical sight distances along the approach should be consistent with observed operational speeds gathered during Step 1B above.	The resulting analytical steps ensure that the approach to the hazard is free of any inherent design shortcomings that have the potential for confounding the intended sight distance diagnosis.

Step #2C. *Examine Hazard Location with respect to possible DSD Warrants*	
Procedure	Product/Application
AASHTO *Design Policy* (e.g., page 115, section on Decision Sight Distance) notes a distinction between typical stopping sight distances and those in which drivers are required to make complex decisions, i.e., in which drivers require perception response time beyond the design value (typically 2.5 s). The Decision Sight Distance criterion applies to a difficult-to-perceive information source in a roadway environment that may be visually cluttered. Therefore, the hazard location needs to be examined for conditions of "visual noise" from competing sources of information, e.g., roadway elements, traffic, TCDs, pedestrians, and advertising signs. Specific sources of visual clutter were also noted in Step 1E above.	When DSD warranting conditions are found to exist, apply the sight distance requirements noted in Table 3-3 (page 116, 2001 AASHTO *Design Policy*) rather than conventional stopping distances based on a 2.5-second perception response time.

Step #2D. *Examine Approach with respect to DSD Warrants*	
Procedure	Product/Application
The approach to the hazard location must also be examined for conditions of visual clutter meeting requirements for DSD application. In particular, these could take the form of advertising signs and/or complex TCDs at intersections along the approach.	Visual clutter along an approach to a hazard detracts from drivers' perception of the hazard. When DSD warranting conditions are found to exist along an approach to a hazard, the distraction is sufficient such that available sight distance to the hazard must be restricted to that distance beyond the distraction.

Step #2E. Examine Traffic Control Devices with respect to MUTCD Criteria	
Procedure	Product/Application
The *Manual of Uniform Traffic Control Devices (MUTCD)* prescribes device placement criteria for signs, signals, and markings. Devices at both the hazard location and along the approach need to be examined for MUTCD compliance.	The output of this step will reveal whether inadequate traffic control device application, e.g., insufficient warning distance or inappropriate warning message, constitute possible sources of driver confusion. Inappropriate or inadequate TCD information can result in longer information processing times, thereby creating an artificial sight distance problem.

<u>Step #3</u>: Apply Accident Data

This step involves the integration of traffic accident data into the analysis. The objective is to locate specific accident-prone locations within the roadway segment which may be indicative of sight distance problems. The practitioner is cautioned that the absence of accidents does not rule out the existence of a sight distance problem, as accidents are probabilistic events and reporting requirements are variable.

Step #3A. Establish Typologies and Frequency by Spot Locations	
Procedure	Product/Application
A review of accident data will reveal the occurrence of various types in close vicinity to the hazard under study. The associated pre-collision paths and their proximity to highway features may suggest the existence of a sight distance problem. Certain accident types are typically associated with specific sight distance problems, e.g.: • Run-off-road, Fixed object **[SSD]** • Side-swipe, rear-end **[PSD]** • Right angle, rear-end **[ISD]**	A collision diagram is used to summarize accident types by location. For examples, see page 211, ITE Manual of Traffic Engineering Studies; and page 1-11 in Hostetter. R.S. and Lunenfeld, H. *Planning and Field Data Collection,* Report FHWA-TO-80-2, Federal Highway Administration, Washington, DC, 1982

Step #3B. Assess Suitability of Accident Sample	
Procedure	Product/Application
While well-documented procedures exist to statistically establish accident causation (see *Accident Research Manual,* Federal Highway Administration Report FHWA/RD-80-/016), this level of sophistication is not necessary for the diagnosis of a sight distance problem. It is desirable (to the extent possible based on available accident data) to establish causation inferences based on accident patterns and to rule out non-sight-distance causal effects.	A reasonable level of confidence (albeit logic-based rather than statistically rigorous) regarding accident causation is possible based on the following: • Inferences based on accident patterns rather than a single event • Occurrences whereby non-sight-distance factors can be logically ruled out

Step #3C. *Examine Potential Sight Distance Causation Effect*	
Procedure	Product/Application
Certain patterns of accident behaviors (i.e., pre-collision maneuver) are suggestive of sight distance problems. For example, single-vehicle or run-off-road occurrences with a fixed object, which may appear visible under some conditions, may not be easily detectable to drivers during conditions of more limited visibility (e.g., darkness). These patterns need to be examined to determine whether sight distance is a potential causal factor, i.e., adequate nighttime sight distance conveyed by TCDs.	A collision diagram can be descriptive of the location and nature of a sight-distance hazard, thus supporting a hypothesis regarding the effect of a sight distance problem.

***Step #4*: Establish Roadway Segments**

The user specifies component roadway approach segments in a manner to support the detailed human factors analysis in Step 5. Separate approach roadway segments are theoretically required for driver PRT and hazard avoidance maneuver functions. The product of this section is a series of driver task diagrams that depict the point where driver actions are required to avoid a potential hazard, information sources which warn of the hazard, and motorist's available sight distances to perform the necessary information-processing and maneuver tasks.

Step # 4A. *Establish and plot action points along approach segment.*	
Procedure	Product/Application
Identify and plot specific locations within the study roadway section requiring a driver action (e.g., maneuver). For example, the hazard under study is the key point where action (e.g., decelerating to the posted speed) is likely required. Where a maneuver (e.g., decelerating) is necessary prior to reaching the hazard, the "action point" is the point where the maneuver is initiated (e.g., end of the decision distance). In the event that the approach roadway section requires some intermediate action, e.g., merging from a dropped traffic lane, this action also needs to be identified and plotted. Action points on the site diagram prepared in Step 1 above should be indicated on the diagram by the symbol A. A series of sequential action points may be designated as $A_{1,}$ A_2 etc.	The developed site diagram will indicate specific points where vehicle actions are required. Examples are as follows: 1. Approach maneuver (such as slowing) as required by the hazard under study 2. Any intermediate actions, e.g., required lane change, on the approach to the hazard under study. Note: Example plots of designated roadway segments (e.g., including appropriately labeled action points) are shown in the example diagnostic procedure application **[Section 5.5].**

Step # 4B. *Establish and plot information sources and associated sight distances along approach segment.*	
Procedure	Product/Application
Any driver action (e.g., hazard avoidance) must be based on information available to the driver. In this step, it is necessary to locate and document driver's information sources providing information for an intended action. Information to the driver should be available from (1) detection of the hazard, and/or (2) traffic control devices pertaining to the hazard. The following information/detection sources were noted on the site diagram in Step 1-I. In this step, separate plots of component information-processing segments may be helpful. • Initial point of sight distance to the hazard by the symbol $\Sigma\Delta_{HAZ}$. • Location of TCD providing information regarding the hazard by the symbol TXΔ. • Initial point of sight distance to the applicable TCD by the symbol $\Sigma\Delta_{TX\Delta}$	The developed site diagram will indicate specific points where information pertaining to the hazard is available to the driver. Examples are as follows. 1. Point of initial detection opportunity on an approaching of both the hazard and any traffic control device warning of the hazard. 2. Specific locations of any TCDs advising of the hazard. NOTE: In the event that the hazard under study is not detectable (i.e., defined in the visual field), the symbol $\Sigma\Delta_{HAZ}$ would not appear on the diagram. In such instances the required sight distance to action point (**A**) will be determined in Step 5.

Step # 4C. *Define component driver response sections within approach segment.*	
Procedure	Product/Application
Distinctly different driver information-processing tasks are associated with each detection and maneuver activity. In this step, roadway sections will be designated and plotted to illustrate the required travel distances over which the driver would perform these varied information-processing and maneuver tasks. Depending upon physical characteristics of the roadway section under study, four distinct driver response cases are the following: Case 1. Direct line of sight to hazard $\Sigma\Delta_{HAZ}$--------→ A Case 2. Intervening traffic control device, i.e., warning of hazard $\Sigma\Delta_{TX\Delta}$-----→$\Lambda\Delta_{TX\Delta}$--->**TCD**-----→A Case 3. Intervening, e.g., distracting, hazard (A_2) within sight line of first hazard (A_1) $\Sigma\Delta_{HAZ1}$---→ $\Sigma\Delta_{HAZ2}$---→A_2---→A_1 Case 4. Intervening traffic control device and distracting hazard $\Sigma\Delta_{TX\Delta}$ --→$\Lambda\Delta_{TX\Delta}$-->**TCD** --→ **SD_{HAZ2}** -→A_2--→A_1	The product of this step is a diagrammed set of roadway component sections, each corresponding to a specific information-processing and maneuver driver task. The distance over which a driver can react to a detectable hazard is the roadway section, **SD_{HAZ}**–A. In this roadway section the driver would detect the hazard and perform any required preparatory maneuver, e.g., decelerating. Likewise, the distance over which a driver reacts to an advance traffic control device is the roadway section **SD_{TCD} – TCD**. In this roadway section the driver has the opportunity to detect the sign, and comprehend the sign's message. The message becomes readable at the point, $\Lambda\Delta_{TX\Delta}$ (i.e., the legibility distance from the sign), which will be computed and located during Step 5. In the final approach section to the hazard, **TCD -- A**, the driver would complete the decision-making and maneuver tasks.

***Step #5*: Analyze Component Driving Task Requirements**

In this step the practitioner applies human factors principles, i.e., comprising information-processing and decision-making criteria, to ensure the adequacy (or to quantify the shortcoming) of the approach roadway to allow for time/distance hazard avoidance requirements.

Step #5A. *Determine the relevant geometric design sight distance application.*

Procedure	Product/Application
The analysis of driving task requirements involves application of the appropriate sight distance value for the given task. Sight distance requirements (to accommodate both the information processing and maneuver tasks) approaching action points(A)will fall into one of the following categories (depending upon roadway environment condition) which were identified in Section 5.2. These are: • Stopping sight distance (SSD) **[Section5.2.1]** • Intersection sight distance (ISD) **[Section5.2.2]** • Decision sight distance (DSD) **[Section5.2.3]** • Passing sight distance (PSD) **[Section5.2.4]**	The result of this task is the specification of the applicable procedure, e.g., engineering design formula, for the computation of $\Sigma\Delta_{HAZ}$ corresponding to each identified hazard or action point. The required sight distance based on application of the appropriate design formula is applied to determine the required length of the roadway segment under study.

Step #5B. *Determine driving task requirements within each component roadway segment.*

Procedure

Driver information processing demands vary as a function of environmental factors, according to the four cases indicated below. Identify separate PRT and MT components of the driving task apply to each of the four cases **[Section 5.2]**. Specific values of PRT and MT will be determined subsequently determined.

Case 1:

Direct line of sight to hazard; no traffic control

$\Sigma\Delta_{HAZ}$--------→ A

In this case, PRT and MT are determined from Section 5.2.

Case 2:

Intervening traffic control device, warning of hazard

$\Sigma\Delta_{TX\Delta}$-----→$\Lambda\Delta_{TX\Delta}$--->**TCD**-----→A

$\Sigma\Delta_{TX\Delta}$-----→$\Lambda\Delta_{TX\Delta}$

Driver must detect traffic control device.

$\Lambda\Delta_{TX\Delta}$--->**TCD**

Driver must read or otherwise comprehend message and may begin decision process. (Legibility distance will be determined in Step 5C.)

TCD-----→A

Decision and maneuver must be completed.

Case 3:

Intervening, distracting hazard at A_2 within sight line of first hazard at A_1.

$\Sigma\Delta_{HAZ1}$---→ $\Sigma\Delta_{HAZ2}$---→A_2---→A_1

$\Sigma\Delta_{HAZ1}$---→ $\Sigma\Delta_{HAZ2}$--→A

Driver requires longer PRT due to complex visual scene ahead. Consider DSD application.

$\Sigma\Delta_{HAZ2}$---→A_2---→A

Driver may require longer MT due to complexity of maneuver and visual scene.

Case 4:

Intervening traffic control device and distracting hazard at A_2 within sight line of first hazard A_1.

$\Sigma\Delta_{TX\Delta}$ --→$\Lambda\Delta_{TX\Delta}$-->**TCD** --→ **SD_{HAZ2}** -→A_2--→A_1

$\Sigma\Delta_{TX\Delta}$-----→$\Lambda\Delta_{TX\Delta}$

Driver must detect traffic control device

$\Lambda\Delta_{TX\Delta}$--->**TCD**

Driver must read or otherwise comprehend message and may begin decision process

$\Sigma\Delta_{HAZ2}$---→A_2---→A

Driver may require longer MT due to complexity of maneuver and visual scene.

Step #5C. *Quantify the applicable PRT and MT requirements for each driving task component.*

Procedure

The general model to be applied for quantifying driver task requirements (i.e., required PRT and MT) is the following: $\Sigma\Delta_{TX\Delta}$**-----→**$\Lambda\Delta_{TX\Delta}$**--->TCD-----→**A. Driver task requirements are determined for each task as follows.

No TCDs present:

$\Sigma\Delta_{HAZ}$**--------→** A

Apply applicable PRT and MT requirement corresponding to predetermined condition, i.e., SSD, ISD, DSD, or PSD as determined in Step 5A.

TCDs present:

$\Sigma\Delta_{TX\Delta}$**-----→**$\Lambda\Delta_{TX\Delta}$

Drivers should be able to detect a TCD prior to time required to comprehend its message. 2.5 s is desirable, although less time may be adequate, e.g., second, third, etc. in a sequence.

$\Lambda\Delta_{TX\Delta}$**--->TCD**

$\Lambda\Delta_{TX\Delta}$ is the "legibility distance", i.e., the approach distance a traffic control device message is comprehended. A detailed discussion below addresses the $\Lambda\Delta_{TX\Delta}$ for signs. In the case of pavement markings, it is the advance distance at which the marking is visually recognized.

The $\Lambda\Delta_{TX\Delta}$ a sign is the distance at which its legend is read or its symbol message is comprehended. PRT requirements **[Ontario Traffic Manual]** for signs consist of sign message legend and symbol reading times as follows:

Reading Time = 1*(number of symbols) + 0.5*(no. of words and numbers) [secs]

For messages exceeding 4 words, the sign requires multiple glances and the driver must look back to the road and at the sign again. Therefore, for every additional 4 words and numbers, or every 2 symbols, an additional ¾-second should be added to the reading time.

TCDs present (Cont.):

The minimum reading time is 1 second. If there are more than 4 words on a sign, a driver must glance at it more than once, and look back to the road and at the sign again. For every additional 4 words and numbers, or every 2 symbols, an additional 3/4 second should be added to the reading time.

This segment must be sufficient in length to accommodate the reading time noted above. However, its length is constrained by letter height, i.e., limited to 40 feet for every inch of letter height. For example, a 4-inch letter-height sign must be read within a distance of 4 X 40 = 160 feet. On a 40 mph (58.8 fps) roadway, the driver is limited to a maximum of 160/58.8 or 2.7 seconds to read the sign. Moreover, the traffic engineer must consider that the driver can not be expected to fixate on the sign.

Decision Time, i.e., to make a choice and imitate a maneuver if required. Considering the driver's alerted state having read the sign, decision time can range from one second for commonplace maneuvers (e.g. stop, reduce speed) to 2.5 seconds or more when confronted with a complex highway geometric situation.

$\Lambda\Delta_{TX\Delta}$**--->TCD-----→**A

While the required MT may be initiated prior to passing the TCD, it must be completed in the above-noted segment. MT values associated with designed sight distance considerations are treated herein **[Section 5.2]**. Additional literature sources of extensive maneuver time data are available **[Lerner, N.D., Steinberg, G.V., Huey, R.W., and Hanscom, F.R., 1999]**

Step #5D. *Assess the adequacy of the available sight distance components.*	
Procedure	Procedure (continued)
Case 1: *Direct line of sight to hazard; no traffic control* $\Sigma\Delta_{HAZ}$**--------**→ A Does the subsection length $\Sigma\Delta_{HAZ}$→ A allow sufficient time for the driver to perform any required hazard avoidance maneuver? Case 2: *Intervening traffic control device, warning of hazard* $\Sigma\Delta_{TX\Delta}$**-----**→$\Lambda\Delta_{TX\Delta}$**--->TCD-----**→A Does the subsection length, $\Sigma\Delta_{TX\Delta}$→$\Lambda\Delta_{TX\Delta}$ allow sufficient time (minimum1.5 seconds) for the driver to detect the traffic control device? Does the subsection length, $\Sigma\Delta_{TX\Delta}$→TXΔ allow sufficient time for the driver to detect and read the traffic control device? Does the subsection length, TXΔ→**A** allow sufficient time for the driver to perform any required hazard avoidance maneuver?	Case 3: *Intervening, distracting hazard at A_2 within sight line of first hazard at A_1.* $\Sigma\Delta_{HAZ1}$**---**→ $\Sigma\Delta_{HAZ2}$**---**→A_2**---**→A_1 Does then subsection length $\Sigma\Delta_{HAZ1}$→ A_1 allow sufficient time for the driver to process and respond to the intervening distraction (i.e., apply DSD criteria) and perform any required hazard avoidance maneuver? Case 4: *Intervening traffic control device and distracting hazard A_2 within sight line of first hazard A_1.* $\Sigma\Delta_{TX\Delta}$ **--**→$\Lambda\Delta_{TX\Delta}$**-->TCD --**→ **SD_{HAZ2} -**→A_2**--**→A_1 Does the subsection length, $\Sigma\Delta_{TX\Delta}$→$\Lambda\Delta_{TX\Delta}$ allow sufficient time (2.5 s desirable; minimum 1.0 to 1.5 s) for the driver to detect the traffic control device? Does the subsection length, $\Sigma\Delta_{TX\Delta}$→TXΔ allow sufficient time for the driver to detect and read the traffic control device? Does the subsection length, TXΔ→**A_1** allow sufficient time for the driver to process and respond to the intervening distraction (i.e., apply DSD criteria) and perform any required hazard avoidance maneuver?

***Step #6*: Develop Engineering Strategies for Amelioration of Sight Distance Deficiencies.**
In this final step the practitioner recommends improvement, e.g., traffic control device applications or minor design modifications to correct deficiencies.

Step #6A. Apply traffic engineering and highway design principles to component sight distance deficiencies.

Problem	Solution
In Case 1: Direct line of sight to hazard; no traffic control $\Sigma\Delta_{HAZ}$--------→ A Available sight distance to hazard, $\Sigma\Delta_{HAZ}$, is less than required based on Step 5B results.	Add warning traffic control device, increasing warning distance as shown in case 2 below.
In Case 2: Intervening traffic control device, i.e., warning of hazard $\Sigma\Delta_{TX\Delta}$-----→$\Lambda\Delta_{TX\Delta}$--->**TCD**-----→A Total available sight distance less than the required sight distance from Step 5C.	<u>If $\Lambda\Delta_{TX\Delta}$--->**TCD** is inadequate, i.e., information overload.</u> Apply "information spreading" by adding more devices, each with less information. Increase legibility distance, e.g., by increasing letter size. <u>If $\Lambda\Delta_{TX\Delta}$--->**TCD**-----→A is inadequate.</u> Increase warning distance, $\Sigma\Delta_{TX\Delta}$→$\Lambda\Delta_{TX\Delta}$ via improving the TCD's legibility distance. Apply larger device, increase letter size. In DSD condition, add conspicuity device, e.g., flashing beacon or consider ITS application. <u>If $\Sigma\Delta_{TX\Delta}$-----→$\Lambda\Delta_{TX\Delta}$--->**TCD** is inadequate.</u> Reduce information load on existing TCDs. Apply additional TCDs (e.g., delineation devices, advance supplemental devices) to convey essential information.
Case 3: $\Sigma\Delta_{HAZ1}$---→ $\Sigma\Delta_{HAZ2}$---→A_2---→A_1 Available sight distance to hazard, $\Sigma\Delta_{HAZ}$, is less than required based on Step 5B results.	Add warning traffic control device, achieving increased warning distance.
Case 4: $\Sigma\Delta_{TX\Delta}$ --→$\Lambda\Delta_{TX\Delta}$-->**TCD** --→ **SD_{HAZ2}** -→A_2--→A_1 Total available sight distance less than the required sight distance from Step 5C.	Apply combination of Case 2 solutions noted above.

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Attachment A: Example Application: Sight Distance Diagnostic Procedure

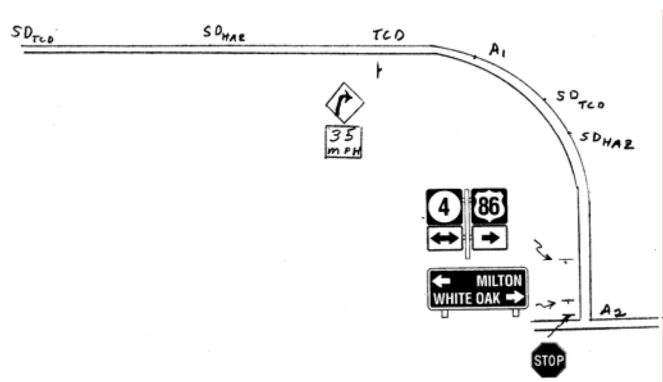
The example driving situation consists of a 55-mph, two-lane rural roadway which approaches a 35-mph curve followed by a Stop-controlled intersection. The intersection approach is to a main highway, i.e., requiring application of destination guide signing.

Driver requirements in this situation are as follows:

1. Reduce speed from 55 to 35 m.p.h. to negotiate curve
2. Process traffic control device information related to intersection, e.g., Destination name sign
3. Stop for intersection

1. Step 1- Collect Field Data and Prepare Site Diagram

The labeled site diagram is shown below.



Example Site Diagram

2. Step 2- Conduct Preliminary Engineering Analyses

This example requires a sight distance analysis to two separate potential hazards. The first is a 35 mph curve which requires slowing from 55 mph; and the second is an intersection which is heavily signed with a Stop sign and two guide signs, containing multiple route shields, symbols, and destination names. The approach roadways to each hazard point are separately treated as follows: (1) curve approach, and (2) signed intersection approach.

2.1 Curve Approach Segment

Steps 2A thru 2D – Examine Site with respect to AASHTO Design and DSD Criteria

For the purpose of this example, it is assumed that geometrics conform to AASHTO and that DSD criteria (e.g., visually cluttered environmental conditions) do not apply.

Step 2E – Examine Traffic Control Devices for Compliance with the MUTCD

Chapter 2C of the MUTCD specifies requirements for warning signs. The curve warning sign in the example is a “W1-2, Horizontal Alignment Sign” with a 35-mph advisory speed plate. Section 2C-05 of the MUTCD specifies an “advance placement guideline” for warning signs. Given the requirement to slow from 55 to 35 mph, the recommended distance in Table 2C-4 is 350 feet.

2.1.1 Signed Intersection Approach Segment

Steps 2A thru 2D – Examine Site with respect to AASHTO Design and DSD Criteria

For the purpose of this example, it is assumed that geometrics conform to AASHTO and that DSD criteria (e.g., visually cluttered environmental conditions) do not apply.

Step 2E – Examine Traffic Control Devices for Compliance with the MUTCD

This segment is a stop-signed intersection approach containing signs to multiple routes and destinations.

Chapter 2D of the MUTCD provides requirements for guide signs on conventional roads. Signs in the example consist of a “directional assembly” with destination name signs and route shields. Required advance distances and spacing of these signs is given in Figure 2D-2. Typically, when a series of guide signs is sequentially placed along the approach to an intersection there is a 100-to-200 foot separation between the first two signs. The minimum spacing between signs is 100 feet, i.e., intended to enable drivers to read the entire message on either sign. Section 2D.06 requires 6-inch letter heights for a 35-mph roadway.

Specifications for Stop sign size and placement are contained in Chapter 2A of the MUTCD. As shown in Figure 2A-2, the Stop sign should be set back a minimum of 12 feet from the intersection. The recommended letter height is 8 inches.

3. Step 4 – Establish Roadway Segments

This example requires a sight distance analysis to two separate potential hazards. The first is slowing from 55 mph to the 35 mph posted curve advisory speed; and the second is a stop signed approach to an intersection containing signs to multiple routes and destinations. As above, the approach roadways are separately discussed.

3.1 Curve Approach Segment

The roadway segment requiring the driver to slow from 55 mph to a 35-mph curve is labeled in accordance with Steps 4A and 4b and is shown below. The two sight distance driver response scenarios are the following:

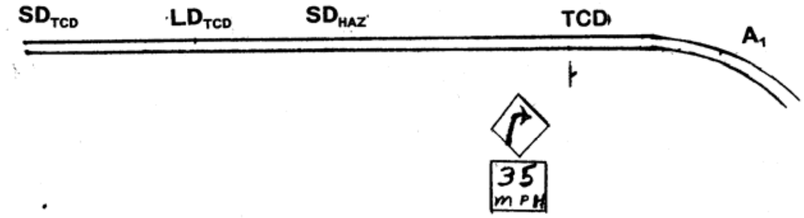
Case 1. Direct line of sight to hazard, i.e., 55-mph speed zone to 35-mph curve

$\Sigma\Delta_{HAZ}$**--------→** A

Case 2. Intervening traffic control device, i.e., 35-mph advisory speed sign warning of hazard

$\Sigma\Delta_{TX\Delta}$**-----→**$\Lambda\Delta_{TX\Delta}$**--->TCD-----→**A

This roadway is diagrammed below.



3.2 Signed Intersection Approach Segment

On this roadway section, 35-mph motorists are confronted with a stop-signed intersection and two guide signs containing destination names and route shields. Due to the fact that sight distance to the intersection is limited by a curve on the approach, a sight distance analysis is critical. The component section diagram is labeled in accordance with Steps 4A and 4b and shown below. The sight distance driver response scenarios are the following:

Case 1. Direct line of sight to hazard, i.e., 35-mph speed zone to intersection

$\Sigma\Delta_{HAZ}$--------→ A

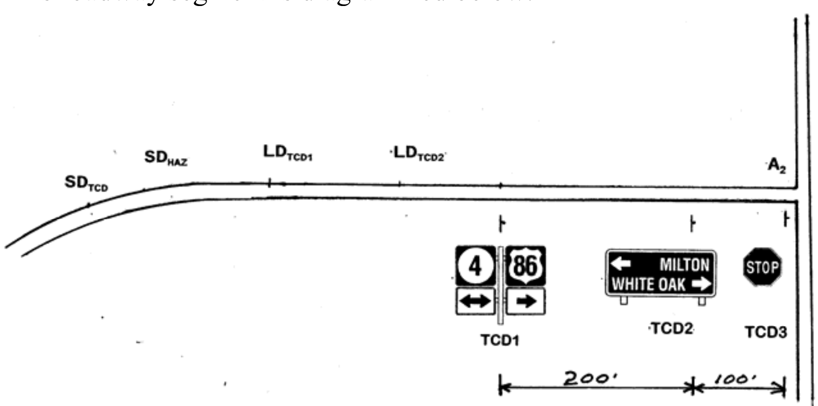
Case 2. Three intervening traffic control devices, i.e.,

A route shield assembly:
$\Sigma\Delta_{TX\Delta1}$-----→$\Lambda\Delta_{TX\Delta1}$--->**TCD1**-----→A

A destination name sign:
$\Sigma\Delta_{TX\Delta2}$-----→$\Lambda\Delta_{TX\Delta2}$--->**TCD2**-----→A

A Stop sign:
$\Sigma\Delta_{TX\Delta3}$-----→$\Lambda\Delta_{TX\Delta3}$--->**TCD3**-----→A

This roadway segment is diagrammed below.



Intersection Approach Segment Diagram

4. Step 5 – Analyze Component Driving Task Requirements

4.1 Curve Approach Segment

The roadway section, requiring the driver to slow from 55 mph to a 35-mph curve, considers sight distance to the curve and legibility distance requirements posed by the advisory speed sign.

Step 5A – Determine the relevant design sight distance application

The applicable design sight distance is *Slowing Sight Distance*, i.e., the required distance ahead for a driver to observe a curve (e.g., potential hazard) ahead and adjust its speed accordingly. In the event that certain visual noise conditions or other factors are present which would render the curve as difficult-to-perceive, then consideration must be given to applicable *Decision Sight Distance* criteria **[Section 5.2.3]**. Where a traffic control device is present, driver information processing time is required to observe and comprehend the sign as well as slow to a safe curve negotiation speed. In the current example, i.e., a rural uncluttered environment, the DSD criterion is not applied.

Step 5B – Determine the driving task requirements

Considering the two possibilities in this case, i.e., Case 1 in which the driver observes the curve ahead without seeing the sign, and Case 2 whereby the driver observes and comprehends the sign, the requirements are as follows:

Case 1. Direct line of sight to hazard, i.e., 55-mph speed zone to 35-mph curve

$\Sigma\Delta_{HAZ}$--------→ A

The sight distance requirement in this case is simply that the driver observes the curve ahead and slows to a safe speed.

Case 2. Intervening traffic control device, i.e., 35-mph advisory speed sign warning of hazard

$\Sigma\Delta_{TX\Delta}$-----→$\Lambda\Delta_{TX\Delta}$--->**TCD**-----→A

The sight distance requirement in this case is that the driver observes the sign, comprehends the sign message, and slows to a safe speed.

Step 5C – Quantify the applicable PRT and MT requirements for each driving task

Case 1. Direct line of sight to hazard, i.e., 55-mph speed zone to 35-mph curve

$\Sigma\Delta_{HAZ}$--------→ A

Recalling that DSD does not apply, the design PRT value of 2.5 s is applied; thus the PRT component of sight distance is 202 feet, i.e., 2.5 s times 80.85 fps. The MT requirement (4.0 s) is derived from the need to slow from 55 mph to 35 mph at a comfortable deceleration rate, i.e., .23g[1], requiring 261 feet. Thus the total PRT and MT sight distance requirement is 463 feet.

It is noteworthy, however, that the 2001 AASHTO *Green Book* acknowledges that its deceleration data may be outdated and that more rapid (albeit uncomfortable) decelerations are common. A typical such deceleration is .35g **[Knipling, 1993]**, resulting in an MT of 2.6s. It is

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[1] Derived from Exhibit 2-25, AASHTO *Policy on Geometric Design of Streets and Highways*, 2001. For safety purposes, wet weather deceleration is considered.

also known that most reasonably alert drivers are able to initiate braking within a PRT of 1.6 s **[Section 5.2.1]**. Applying these performance parameters to slowing from 55 to 35 mph, the total required PRT distance is 129 feet plus 172 feet MT distance, or 301 feet.

It is unlikely that the need to slow to 35 mph would be visually evident from an advance distance of either 301or 463 feet. Therefore, the critical sight distance consideration is based on the application of the speed advisory sign.

Case 2. Intervening traffic control device, i.e., 35-mph advisory speed sign warning of hazard, $\Sigma\Delta_{TX\Delta}$**-----**→$\Lambda\Delta_{TX\Delta}$**--->TCD-----**→A

In this case the driver needs to detect the sign, read the sign, and decelerate to the safe curve speed. A critical requirement for sight in advance of a highway i.e., allowing time to comprehend the sign's message, is known as *Legibility Distance*. There is a considerable body of knowledge regarding sign legibility distance requirements **[Smiley, 2000]**

For simple warning signs, the MUTCD specifies a 250-foot legibility distance for symbol signs (see Table 2C-04) applied in "condition B", e.g., slowing for a curve. Moreover, the MUTCD considers that a deceleration value of 11.2 fpss be applied for determining warning sign placement.

Consider the driving task requirements as follows: 2.0 s are needed to detect and comprehend (e.g., minimum 1.0 s detection time plus 1.0 symbol comprehension) the simple warning sign message prior to the initiation of slowing, the deceleration requirement would be .32g or approximately the equivalent slowing rate of skidding on wet pavement. In this example the required PRT and MT distances would be 161 and 189 feet respectively, for a total of 350 feet.

The MUTCD-recommended warning sign advance placement of 137½ feet (interpolation from Table 2C-04) in addition to the indicated 250-foot legibility distance provides 387½ feet of information lead distance. Therefore the recommended MUTCD warning sign placement in advance of the curve is adequate.

For signs with complex messages, i.e., sets of destination names or symbols in combination with symbols, message comprehension may require significantly more legibility distance. The next example illustrates such a situation.

4.2 Signed Intersection Approach Segment

On this roadway section, 35-mph motorists are confronted with a stop-signed intersection and two guide signs containing destination names and route shields. Since sight distance to the intersection is limited by a curve on the approach, a sight distance analysis is critical.

Step 5A – Determine the relevant design sight distance application

As the driver approaches a Stop-signed intersection, there must sufficient available *Stopping Sight Distance* **[Section 5.2.1]** to enable stopping at the stop line. (While negotiating intersection involves the application of *Intersection Sight Distance*, the current example is limited to approaching the intersection.)

Step 5B – Determine the driving task requirements

Considering the two possibilities in this case, i.e., Case 1 in which the driver proceeds to the intersection ahead while ignoring the signs, and Case 2 whereby the driver observes and comprehends the intermediate signs, the requirements are as follows:

Case 1. Direct line of sight to hazard, i.e., 35-mph speed zone to intersection

$\Sigma\Delta_{HAZ}$**--------→** A

The sight distance requirement (to accommodate travel time) in this case is simply that the driver observes the intersection ahead and safely slows to a stop.

Case 2. Three intervening traffic control devices, i.e.,

A route shield assembly:

$\Sigma\Delta_{TX\Delta 1}$**-----→**$\Lambda\Delta_{TX\Delta 1}$**--->TCD1-----→**$A_1$

A destination name sign:

$\Sigma\Delta_{TX\Delta 2}$**-----→**$\Lambda\Delta_{TX\Delta 2}$**--->TCD2-----→**$A_2$

A Stop sign:

$\Sigma\Delta_{TX\Delta 3}$**-----→**$\Lambda\Delta_{TX\Delta 3}$**--->TCD3-----→**$A_3$

where **TCD1** is a route shield assembly bearing two route designations, **TCD2** is a destination guide sign with two destination names and directional arrows, and **TCD3** is a Stop sign.

The sight distance requirement in this case is that the driver detects and comprehends the signs, and slows to a safe stop at the stop line.

Step 5C – Quantify the applicable PRT and MT requirements for each driving task

Case 1. Direct line of sight to hazard, i.e., speed reduction from 35-mph speed to stop at the stop line.

$\Sigma\Delta_{HAZ}$**--------→** A

The design *Stopping Sight Distance* does not accommodate information-processing requirements of the intervening guide signs. The AASHTO design SSD value **[AASHTO *Green Book*, 2001]** for a 35-mph approach is the range, 225 to 250 feet, which accounts for both the PRT and MT tasks.

It should be noted that the above sight distance would barely accommodate the physical placement of the two guide sign assemblies that are shown in the figure. Moreover, the information-processing load imposed by the signs requires significant attention in terms of sight distance requirements. Therefore the Case 2 condition is treated below.

The general model,

$\Sigma\Delta_{TX\Delta}$**-----→**$\Lambda\Delta_{TX\Delta}$**--->TCD-----→**A

entails the following considerations. First, there must be sufficient sight distance so that the sign is detected prior to time required to comprehend the sign's message, thus application of the $\Sigma\Delta_{TX\Delta}$

term. This advance distance is not specified in the MUTCD. Nevertheless, 2.5 seconds is desirable for this sign detection task, although less time may be adequate as motorists who are looking for signs are generally aware of the expected position in their field of view. The more essential approach sight distance to a traffic control device is that required to comprehend its message.

The symbol in the above model, $\Lambda\Delta_{TX\Delta}$ refers to "legibility distance", i.e., the approach distance at which a TCD legend is read or its symbol message is comprehended. The legibility distance of a legend sign is determined multiplying a "Legibility Index" (i.e., the distance at which a given unit of letter height is readable) by the letter height. The applicable Legibility Index values are shown in the table below. For example, the legibility distance typically associated with 6-inch letter height is 40 times 6 or 240 feet.

Legibility Index:
Legibility distance based on letter height

Metric	**US Customary**
4.8 meters/centimeter	40 feet/inch

The legibility distance of symbol signs has been researched[2] in a laboratory study **[Dewar and Swanson, 1997]** and found to significantly exceed that of legend signs (despite the high degree of variability in the study data). For example, the mean legibility distance for the right curve arrow symbol was determined to be 283 meters (with a standard deviation of 68 meters). Consider that a 55-mph approach allowing a 2.5-second advance sight distance and 1.0-second reading time would consume only 86 meters, pure symbol signs are not expected to result in an information processing problem.

The required PRT for this example roadway segment is comprised of three components, i.e., detection of the signs, comprehending the sign messages, and detecting the intersection. Each is separately discussed.

Sign Detection Upon a driver's detection of the first sign, the second and third would require minimal detection time. The recommended detection time for the first sign is 2.5 seconds; however the second two signs are likely to be detected much more rapidly. "Alerted" PRT responses are known to occur in as little as 1.0 to 1.5 seconds. Moreover, signs can be quickly detected as drivers know where to look for signs and typically scan toward expected sign locations. Therefore, a conservative sign detection PRT for the example roadway segment is (2.5 + 1.5 + 1.5) or 5.5 seconds.

Sign Comprehension Sign comprehension consists of the sign reading task plus the process of making the resultant decision, e.g., right or left turn in response to the sign's information. The PRT requirement[3] is based on sign-response reading and decision time, for which general rules are noted in the table on the next page.

The first guide sign assembly contains two numbers and two symbols, requiring 3.0 seconds of reading time; the second contains two designation name and two symbols, also requiring 3.0 seconds; and the third is a simple and familiar one-word regulatory sign, requiring one second.

[2] See page 97 of the *Traffic Control Devices Handbook* [**Pline, 2001**]
[3] Smiley, Ontario Ministry of Transportation, *Ontario Traffic Manual,* "Sign Design Principles", 2000

Thus the total sign reading time is 7.0 seconds. This estimate is highly conservative, as drivers would likely scan the guide signs seeking only a particular name or route number; however, it is necessary to provide sufficient information-processing sight as some drivers may need the entire set of information. An additional 3.0 seconds is considered for decision time responses to the three signs. Thus the total comprehension time for the three signs is ten seconds.

Sign Comprehension PRT Requirements
Reading Time requirements are: ½ second for each word or number, or 1 second per symbol, with 1 second as a minimum for total reading time. In the event of the sign's containing redundant information, the reading time computation should be limited to critical words. The suggested formula for estimating sign reading time is, reading time (seconds) = 1(number of symbols) + 0.5(number of words and numbers). For messages exceeding 4 words, the sign requires multiple glances and the driver must look back to the road and at the sign again. Therefore, for every additional 4 words and numbers, or every 2 symbols, an additional ¾-second should be added to the reading time. When the driver is sufficiently close to see a sign at an angle, the sign is not visible for the last ½ second. Therefore, ½ second should be added to the required reading time. An exception applies to signs requiring a maneuver before the sign is reached, as no further reading is required. ***Decision Time***, i.e., to make a choice and imitate a maneuver if required. Considering the driver's alerted state having read the sign, decision time can range from one second for commonplace maneuvers (e.g. stop, reduce speed) to 2.5 seconds or more when confronted with a complex highway geometric situation.

Intersection Detection Distance As noted above under the Case 1 ($\Sigma\Delta_{HAZ}$---→ A) discussion, the Stopping Sight Distance Requirement considers a 2.5-second PRT.

A summary of the above-noted PRT requirements, if separately considered, is shown in the table below.

Driving Task	PRT Requirement (seconds)
Perceive initial guide sign	2.5
Perceive next 3 signs, @ 1.5 s	4.5
Comprehend initial guide sign	4.0
Comprehend second guide sign	4.0
Comprehend Stop Sign	2.0
Perceive intersection	2.5
Total	19.5

The above sum of PRT requirements would apply to a serial task process. However, a realistic assessment of PRT requirements considers that many the above tasks are concurrent. For example, the Stop sign comprehension and decision-making tasks would not logically entail a separate process of perceiving the intersection, thus conceivably reducing the total PRT by 2.5 seconds. In addition, following a driver's 2.5-second detection of the initial sign, the subsequent two signs would likely be detected with a minimum detection time (e.g., 1.0 seconds rather than 1.5 seconds), thus conceivably reducing the total PRT by another 1.0 second. Therefore, subtracting 3.5 seconds from the serial total of 19.5 seconds, the estimated PRT requirement becomes 16.0 seconds.

The MT requirement, i.e., to slow from 35 mph to a stop at the specified AASHTO g-force, calculates to 4.7 seconds over a distance of 120 feet. The extent to which the deceleration process would occur concurrently with the various sign-response tasks is uncertain. However, it is logical (and best serves liability concerns) to allow time for comprehension of all signs prior to the initiation of the slowing response.

Therefore the overall sight distance requirement is 16.0 seconds of sign information processing at 35 mph (51.45 fps) or 823 feet, plus the 120-foot deceleration distance, for a total of 943 feet.

A final consideration is the necessity that drivers have sufficient time to comprehend a sign's message during the interval when the message is discernable. Therefore, an essential sight distance diagnostic step is to compare the available sign legibility distance (i.e., available reading distance) with distance traveled during reading PRT (i.e., required reading distance and decision time). The table below contrasts the distance traveled during PRT with the legibility distance. While the guide signs in this example accommodate both reading time and associated decision time, the decision component of PRT can obviously be accomplished after the driver passes the sign.

	Legibility Distance, ft	PRT Distance, ft
Sign #1 6-inch letters, 2 Numbers + 2 Symbols	240	231
Sign #2 6-inch letters, 2 Numbers + 2 Symbols	240	231
Sign #3 8-inch letters, 1 Word	Word, 320 Symbol,	51

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